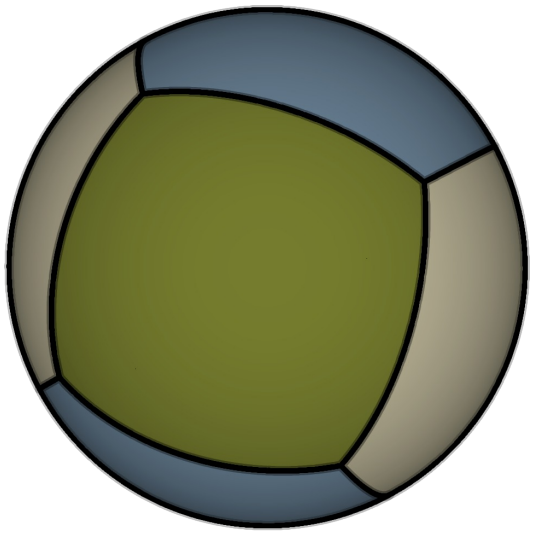
The Complete Homemade Juggling Beanbag Guide

6-Panel Spherical Cube 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.

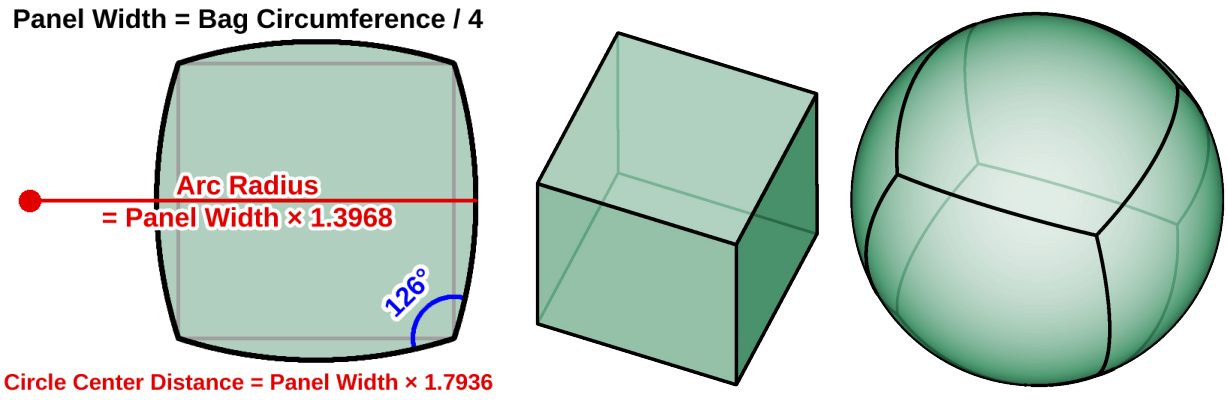
If this guide is useful to you, please **consider donating at my website** linked on the left. I am not monetizing the guide, and I am in need of income.

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.

6-PANEL SPHERICAL CUBE INSTRUCTIONS



My original denim bag, which used steeper panel curves.

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Design Notes

With certain color arrangements this design is reminiscent (to me) of those cubic, wooden alphabet blocks for children and therefore can have a playful, childish aesthetic. Aside from that, it is good for those who enjoy the simplicity and smoothness of minimal seams, but with good roundness and uniformity, or the visual aesthetic of the cube.

The cube is also quick and easy to construct (a bit quicker and easier than the octahedron). It is **more nearly round than the tetrahedron**, and **more uniform than the orange peel ball**, and feels better in my hand than those designs. But it **will still feel a little angular across the seams when made with a non-stretch fabric**. **Pressing the completed ball against a hot iron 🖷 along all the seams will smooth and round the seams and reshape the panels into a more spherical shape.** My cube made with my stiff, non-stretch design testing fabric became perfectly spherical after I ironed it.

A stretchy fabric would probably make this a **great stress-reliever squash ball** due to its large and evenly distributed seamless areas that would stretch well when the bag is squeezed.

For a cube aesthetic but much better roundness, take a look at the 12-panel Simplified Volleyball/Cube 🖷 design.

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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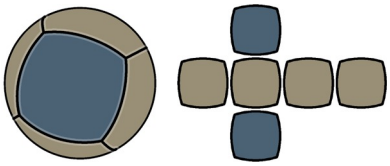
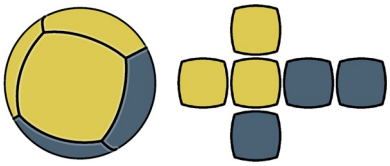
There are seven good color arrangements for this design (possibly more that I haven't thought of), not including the obvious 1 and 6-color options. The following examples are grouped according to the number of colors they contain.

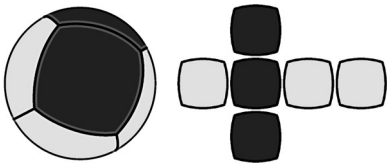
2 colors



#1: Belt. Color A on a pair of opposite panels and a belt of color B on the four panels around the middle.

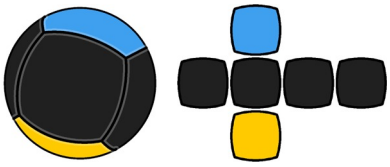


#2: Hemispheres. Color A on one hemisphere (three panels that share a corner) and color B on the other hemisphere.

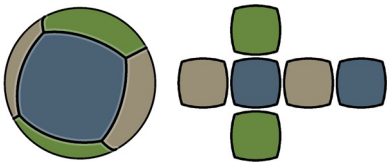


#3: Baseball. Color A on a row of three panels and color B on the other three, forming a tennis ball/baseball layout.

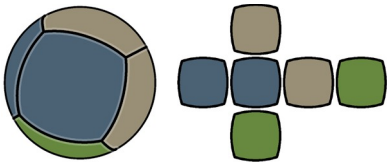
3 colors



#4: Belt with Dichromatic Poles. In this variation of the Belt arrangement each of the two "polar" panels is assigned a unique color. (This was a much later addition and I used a color palette from my 26-panel design.)

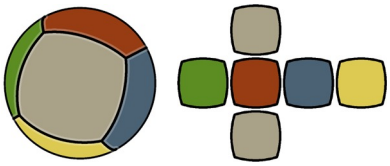


#5: Checker Ball/Patchwork Ball. Each color on pairs of opposite panels (my beanbag photos at the beginning of this chapter and my assembly diagram depict this arrangement).



#6: Three Patches. Each color on pairs of adjacent panels forming three 2-panel swatches that wrap around the ball in each of the three orthogonal directions.

5 colors



#7: Four-Color Belt. This is a variation of the Belt arrangement. Use a neutral color on two opposite panels and make a belt of four bold colors around the middle.

Making the Panels

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1. You will need 6 panels, and **you will be tracing the patterns onto the back of the fabric (the side that will be inside the bag)**. If you use a cutting template, first trace that.

   If you are using something like **corduroy, denim, or a striped fabric, or other woven fabric**, I recommend **orienting the template parallel to the fabric's grain, or so that the cords or stripes run from side to side** (rather than diagonally) and then orienting the panels as shown in my assembly instructions. This will **balance the fabric's direction of stretch** so the ball is not lopsided or otherwise non-spherical. It will also give the ball an attractive aesthetic.

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).

3. Cut out the panels.

Assembly

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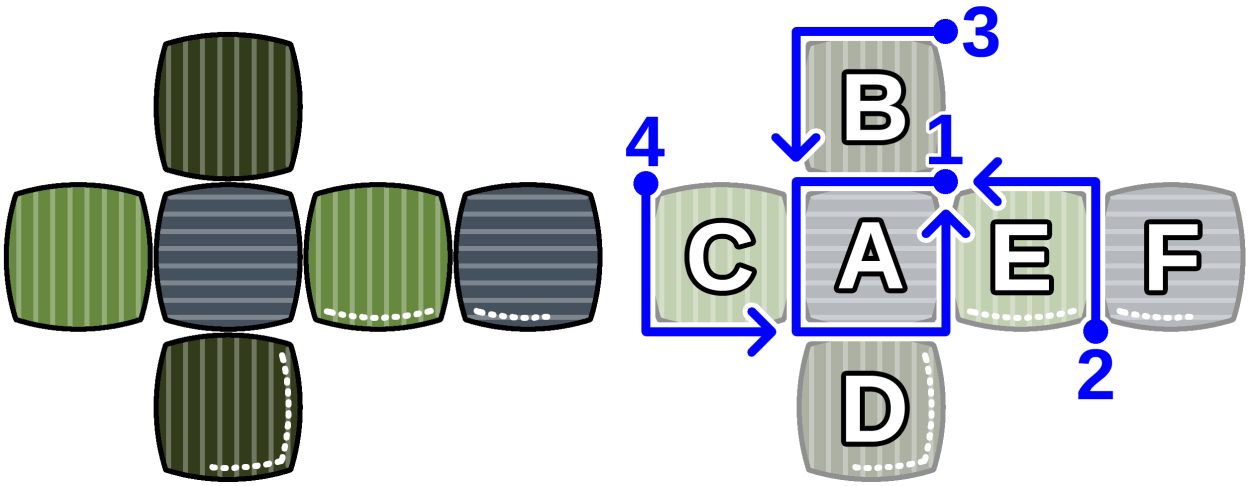
My preferred method of assembly is depicted below and uses 4-5 threads. **The letters in the second illustration indicate the sequence in which the panels are attached**. **Each numbered stitching path in that illustration is a new thread**, but if your thread is long enough you can continue #1 into #2 (reversing 2's direction) and even across the D-F seam (if you don't need that seam open to turn the bag out through) and down the second leg of #4 (C-D). The final seam or two (D-E and optionally D-F) will be sewn from the outside along the dashed lines in the layout diagram.

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



1. **Lay the panels out as shown** in the diagram above (I prefer to place them front face up) and **arrange them according to your color pattern**. **The hatching lines serve as a guide** if you are using a woven fabric, or something like corduroy or a striped fabric. Orienting the lengthwise/straight grain of the fabric in this way will **balance the fabric's stretch** and prevent a lopsided shape, and with a corded or striped fabric it makes the panels resemble a classic volley ball (each panel is surrounded by panels with perpendicular orientations).

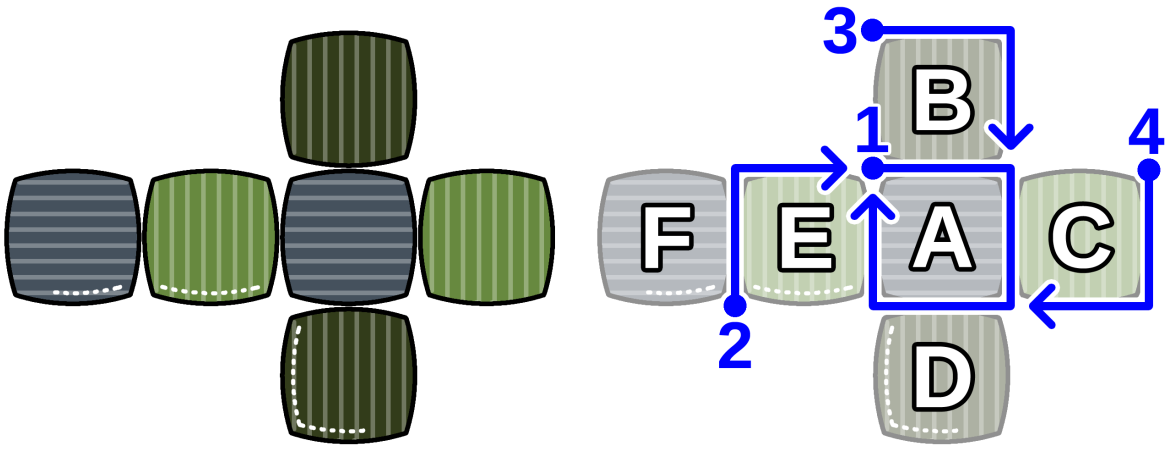
2. Use the stitching template to **draw stitching lines on the *fronts*** of the four panel edges shown with dashed lines in the diagram. My stitching pathway will leave these four edges partially unsewn so the bag can be turned out between them. They will then be **sewn from the outside following the front stitching lines**. (If you use a thin or flexible fabric and don't need such a large opening, just skip marking the bottoms of D and F.) 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 ⅛″ (3mm) apart. If you **make these marks on your template first**, you can more easily transfer them onto these and future panels.

3. **Stitching Path #1:** Start with panel A and sew side panels B-E to each of its edges. **Sew them with their front faces together** so the bag will be inside out.
4. **Stitching Path #2:** Add panel F and sew it to E, stitching toward B, and then continue down the side of E, attaching it to B. (Or continue the previous thread up the B-E seam and then across E-F, reversing path #2. You can then proceed across the D-F seam if you don't need that one open for turning the bag out.)
5. **Stitching Path #3:** Sew B to F, stitching toward C, and then continue down the side of B, attaching it to C. Tie and trim the thread.
6. **Stitching Path #4:** Proceeding around the cube in the same manner as the previous two steps, sew C to F and then continue down the side of C, attaching it to D. Tie and trim the thread. At this point the remaining open seam(s) should be the one(s) with the front stitching lines.
7. Start a new thread at either end of the final open seam(s) and **sew a few starter stitches 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**.
8. Before proceeding, **consider ironing the seam allowances flat**; see the **General Information and Techniques** chapter under "Better Seams by Ironing".
9. **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**.
10. **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").
11. **To reshape the finished bag into a better sphere and reduce angularity and lumpiness at the seams, press it against an iron along all the seams** (be sure to use an appropriate heat setting).



Left-handed diagrams. Just move the right-most panel to the left side to convert my layout arrangements to this one.

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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. The patterns are reduced by 7% 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 104% to get the intended ball size.**

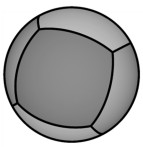
To make the templates, I recommend cutting out the portions of the paper with the patterns you want and using glue or double-sided tape to attach them to your template material, and then cutting along the patterns.

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.

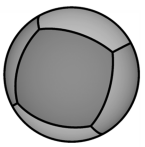
The table below provides the scaling for the ⅛″ increments between my ¼″ sizes. The centimeter grid can be used to verify correct scaling.

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%

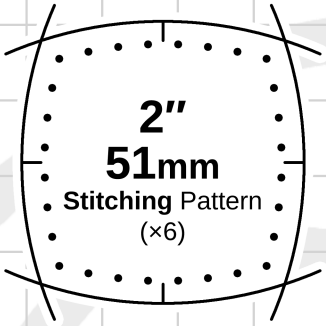


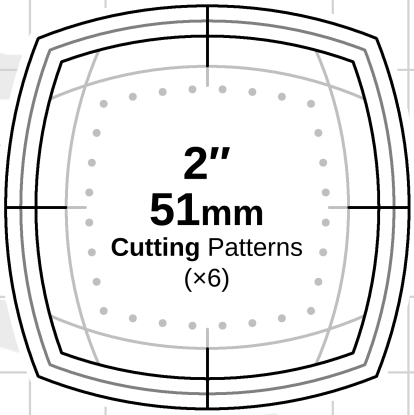
Cube (6 Panels)

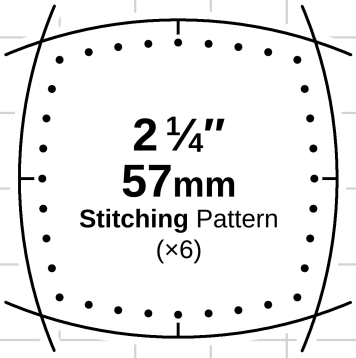
(Pattern sizes are adjusted for corduroy and do not account for gathered seams)

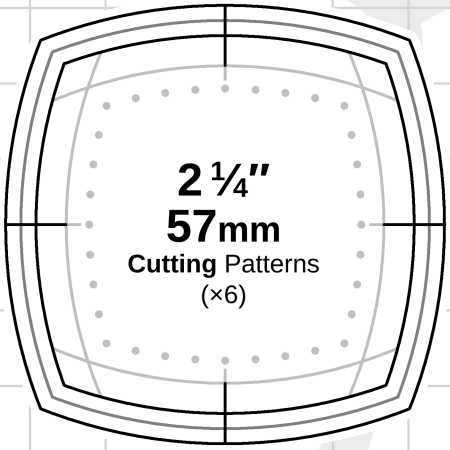


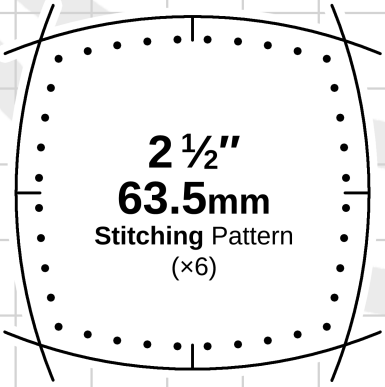
• • • **1mm awl holes for lacing leather balls**
(4mm spacing, 3mm from edge)

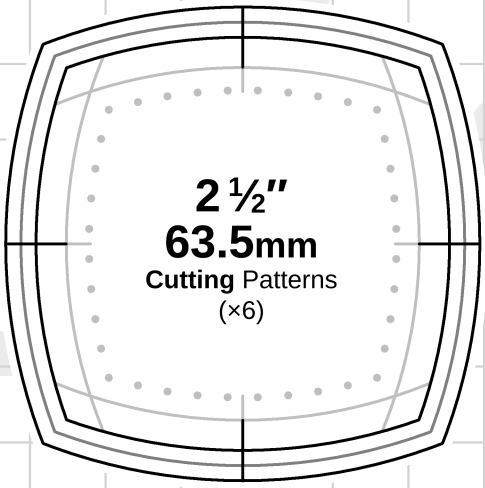


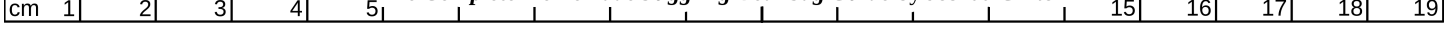


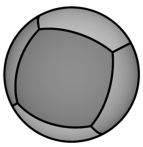






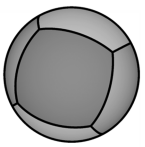






Cube (6 Panels)

(Pattern sizes are adjusted for corduroy and do not account for gathered seams)



• • • **1mm awl holes for lacing leather balls**
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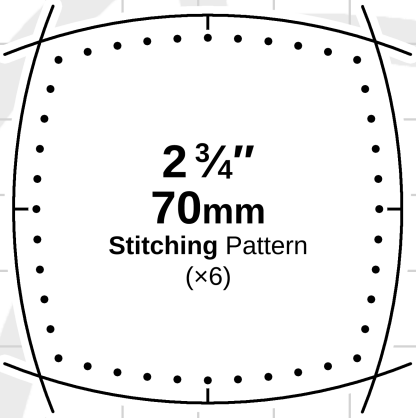

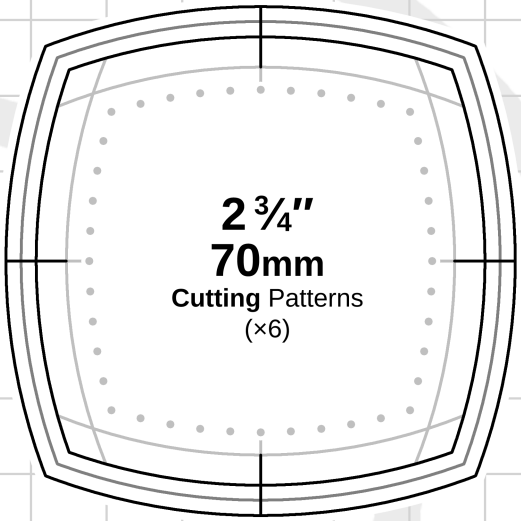

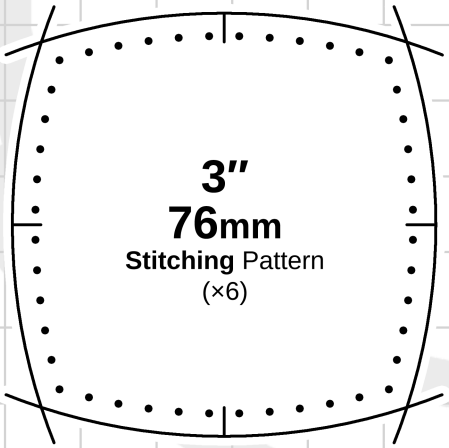

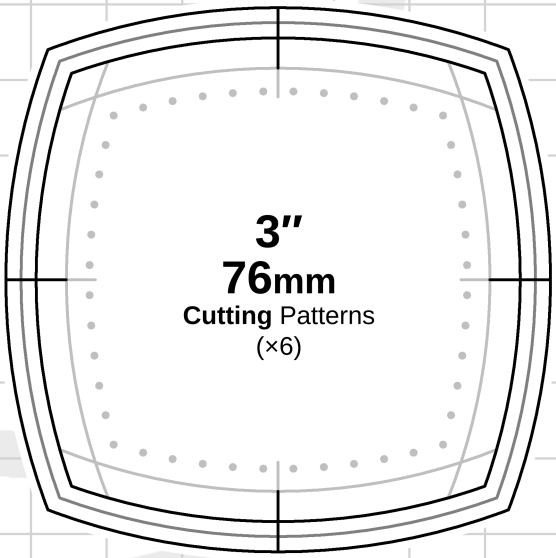

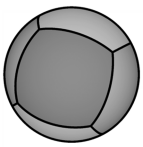

Cube (6 Panels)

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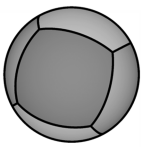
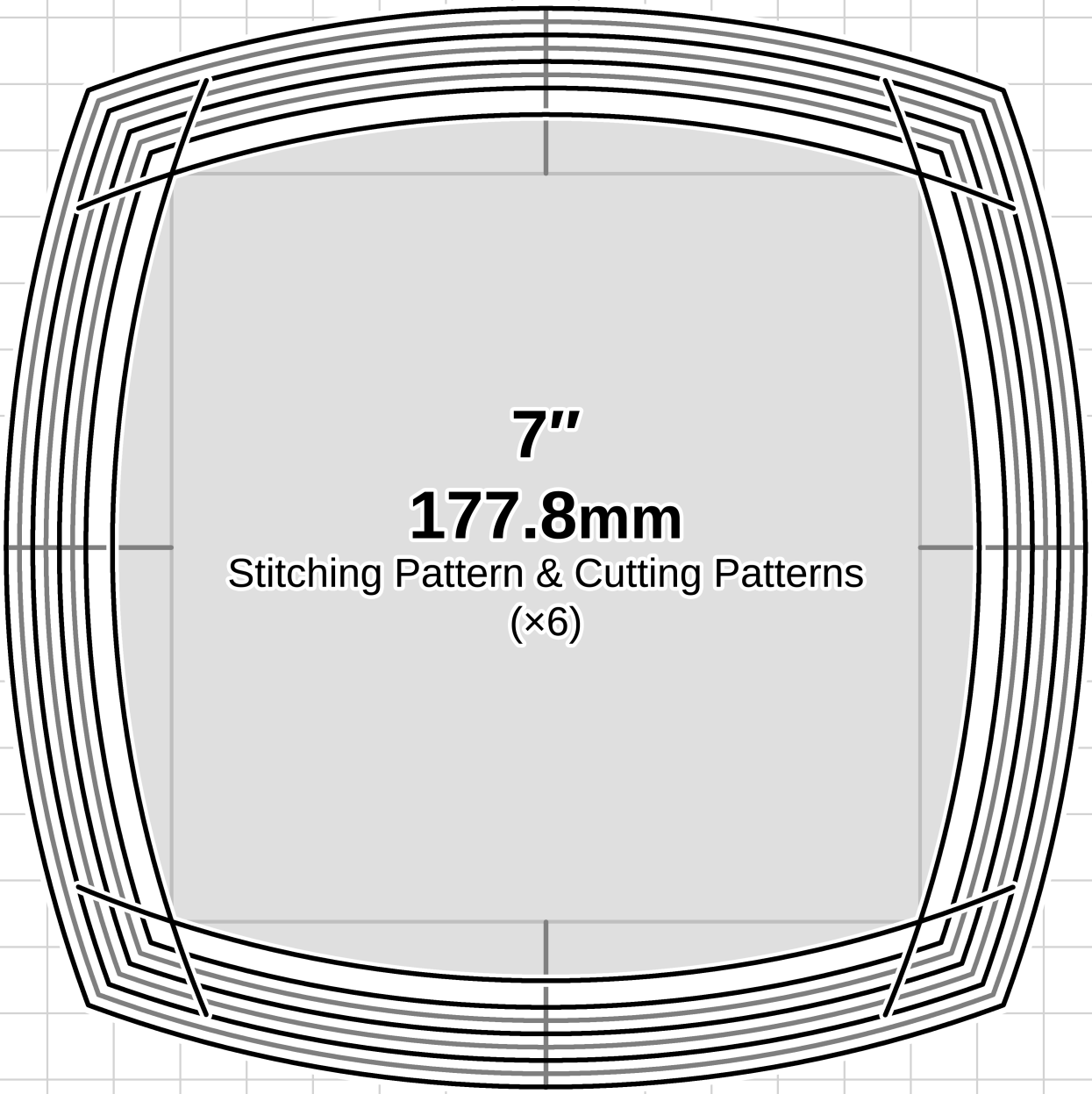


Extra large and versatile pattern for scaling to larger sizes in the Print Dialog. Print twice if you want both a stitching template and a cutting template. The inner pattern (filled with gray) is the stitching pattern. Each dark pattern outside of that marks a 4mm seam allowance interval (at 100% scaling).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



Sizing Formulas for Drawing the Pattern

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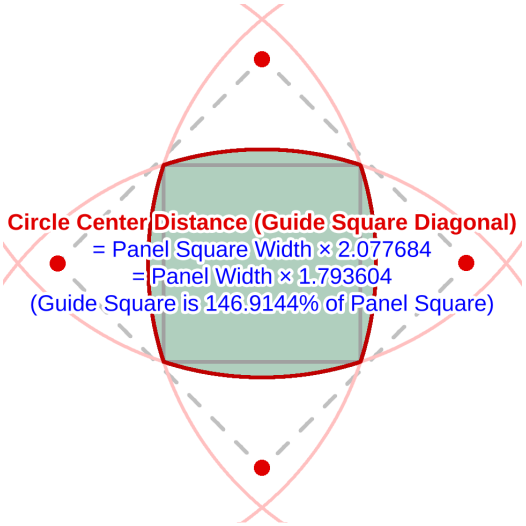
The next section has a table of pre-calculated pattern measurements for all ⅛″ diameter increments from 1¾″ – 3″. Following that are the drawing instructions. If you do not need to create a custom size, skip to that. I provide printable measuring tapes at the end of the **General Information and Techniques** 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 drawing two perpendicular lines that cross at their centers, the ends of which are the circle centers/compass points for the arcs that form the circular square panel shape. The length of those lines are calculated in terms of the desired width of the panel, which is one quarter of the bag circumference. The two lines are the diagonals of an imaginary Guide Square (the dashed gray lines), and the sides of that square are $\sqrt{Diagonal^2/2}$ or *Diagonal* × 0.7071. I use that in my manual drawing instructions to locate the second pair of circle centers using a compass. See the "How to Draw the Panel Shape" section for illustrations of this.



Adjusting for the influence of fabric types on beanbag size

The bag I made with thick corduroy was **5.77 – 8.28%** 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 **7%**. This makes my adjustment factor **1.07**. The bag I made with my design texting fabric which is fairly thin, stiff, tightly-woven, and non-stretch, was 2.76 – 4.77% larger, but that was just for analyzing the shape characteristics of the bag. The bag I made years ago with a thick, stiff, non-stretch denim was 2.5 – 6% larger, but that was my old design.

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 Width = *Diameter* × *π* ÷ 4 ÷ 1.07 (≈ *Diameter* × 0.7854 ÷ 1.07)**
  = *Circumference* ÷ 4 ÷ 1.07
- **Distance between Circle Centers (guide square diagonal) = *Panel Width* × 1.7936**

- **Guide Arc Radius (guide square side) = *Diagonal* ÷ $\sqrt{2}$ ≈ *Diagonal* × 0.7071**
  = *Panel Width* × 1.2683
- **Panel Arc Radius = *Panel Width* × 1.3968**

Forming the panel shape given a starting square

If you want to convert a square into the panel shape by adding curved sides to it, here are the calculations (*s* = square Side length):

- **Circle Center Distance from Side of Square = 0.5388*s***
- **Distance between Circle Centers = 2.0777*s***
- **Arc Radius = 1.6180*s***
- **Resulting Panel Width = 1.1584*s***

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 Panel Arc Radius you calculated above. (18° is the angle between the arcs, or rather tangents thereof, and the edge of the square they span.) If you are working with Radians, omit the $\pi/180$.

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

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 1.07 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 Circle Center Distance and Guide Arc Radius (which just forms the vertical Circle Center Distance), but increase the Panel Arc Radius by the desired seam allowance (I use 8mm). Then center the four new arcs at the same four points. The cutting pattern will be larger than, but parallel to, the stitching pattern.

Finished Diameter	**Circle Center Distance** (guide square diagonal) (mm)		**Guide Arc Radius** (guide square side length) (mm)		**Panel Arc Radius** (mm)		**Panel Width** (mm) (for double-checking)	
	Base	**Adjusted**	Base	**Adjusted**	Base	**Adjusted**	Base	**Adjusted**
1¾″ (44.5mm)	62.616	**58.520**	44.277	**41.380**	48.764	**45.574**	34.911	**32.627**
1⅞″ (47.6mm)	67.089	**62.700**	47.439	**44.336**	52.247	**48.829**	37.405	**34.958**
2″ (50.8mm)	71.562	**66.880**	50.602	**47.291**	55.730	**52.084**	39.898	**37.288**
2⅛″ (54.0mm)	76.034	**71.060**	53.764	**50.247**	59.213	**55.339**	42.392	**39.619**
2¼″ (57.2mm)	80.507	**75.240**	56.927	**53.203**	62.696	**58.595**	44.886	**41.949**
2⅜″ (60.3mm)	84.979	**79.420**	60.090	**56.158**	66.179	**61.850**	47.379	**44.280**

Finished Diameter	**Circle Center Distance** (guide square diagonal) (mm)		**Guide Arc Radius** (guide square side length) (mm)		**Panel Arc Radius** (mm)		**Panel Width** (mm) (for double-checking)	
	Base	**Adjusted**	Base	**Adjusted**	Base	**Adjusted**	Base	**Adjusted**
2½″ (63.5mm)	89.452	**83.600**	63.252	**59.114**	69.662	**65.105**	49.873	**46.610**
2⅝″ (66.7mm)	93.925	**87.780**	66.415	**62.070**	73.146	**68.360**	52.366	**48.941**
2¾″ (69.9mm)	98.397	**91.960**	69.577	**65.026**	76.629	**71.616**	54.860	**51.271**
2⅞″ (73.0mm)	102.870	**96.140**	72.740	**67.981**	80.112	**74.871**	57.354	**53.602**
3″ (76.2mm)	107.342	**100.320**	75.903	**70.937**	83.595	**78.126**	59.847	**55.932**

How to Draw the Panel Shape

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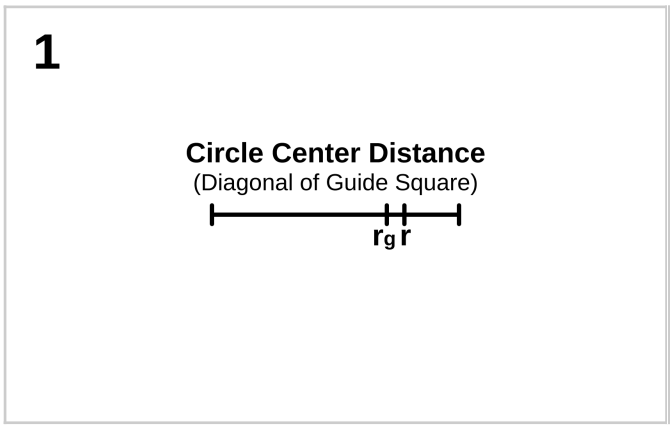
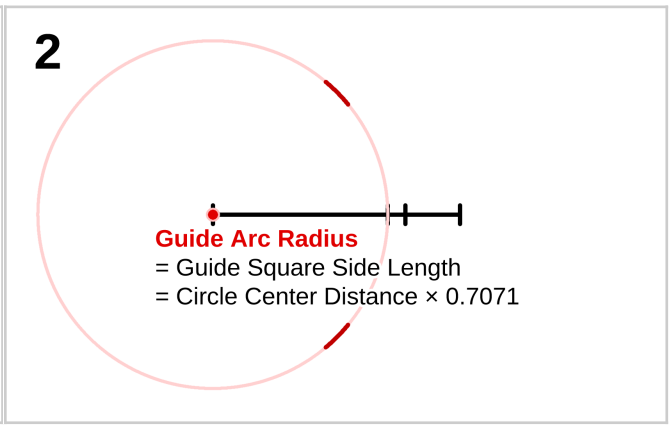
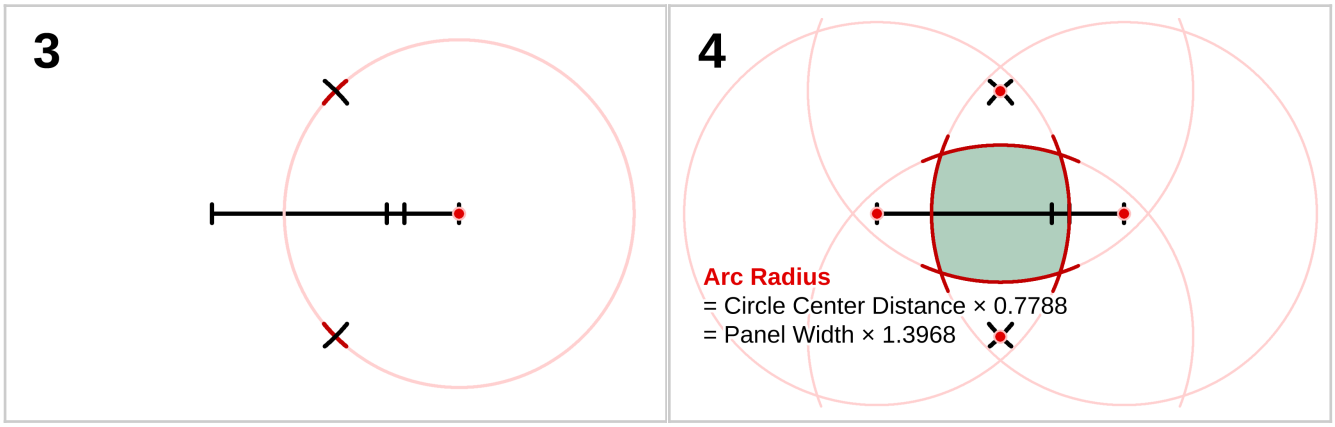
The panel shape is based on a square but has circular sides to produce a more spherical bag. I draw this shape in a similar manner to the basic, circular orange peel shape. The illustrations below show the method and are oriented toward drawing the shape by hand. Their numbers correspond to the step numbers in the manual directions. The manual directions use compass arcs to mark the locations of the two vertical circle centers. The SketchUp directions simply call for a vertical line to be drawn, since that is easy on the computer.

The basic procedure is to draw the four corners of a guide square whose distance between opposite corners is equal to **Circle Center Distance** (from the table above), and then draw arcs/circles of radius **Panel Arc Radius** centered at each of the end points. 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 of length **Circle Center Distance** and mark each end of it. Also mark two points along it: r_g, which is the distance of **Guide Arc Radius** from one end, and r, which is the distance of **Panel Arc Radius** from the same end. You will use these marks to extend the compass to the correct radii.
2. Extend the compass to the **Guide Arc Radius** mark (r_g), and from that endpoint of the line draw partial arcs above and below the middle of the line.
3. Place the compass on the opposite endpoint and draw two more arcs to produce two X-shaped intersections. You have now formed the four corners of the Guide Square, depicted in Illustration 3 by the dashed gray lines, which are the compass points to use in forming the panel shape.
4. Extend the compass a bit farther to the **Panel Arc Radius** mark (r) and draw four arcs, two centered at the endpoints of the line, and two centered at the arc intersections you made in the previous step. This forms the circular square, whose width and height should equal **Panel Width**.
5. To draw a cutting pattern, increase the Panel Arc Radius by the desired seam allowance (I use 8mm) and then draw four arcs centered at the same four points as in the previous step.

SketchUp directions

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

1. Draw two perpendicular lines of length **Circle Center Distance** and center them on each other.
2. Draw circles of radius **Panel Arc Radius** centered on all four ends of the lines. The intersection of the four circles forms the circular square. Its width and height should equal **Panel Width**.
3. To draw a cutting pattern, draw the same starting lines but increase the circle radii by the desired seam allowance (I use 8mm).

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

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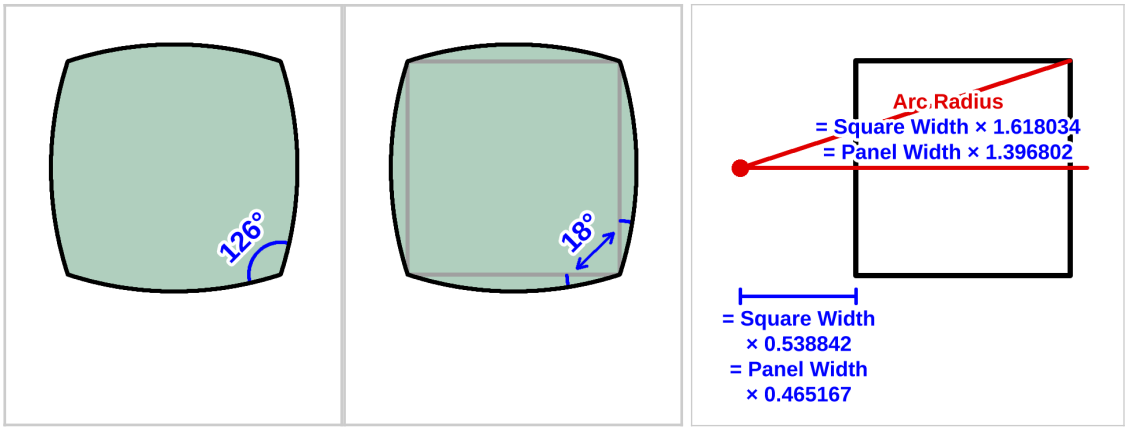
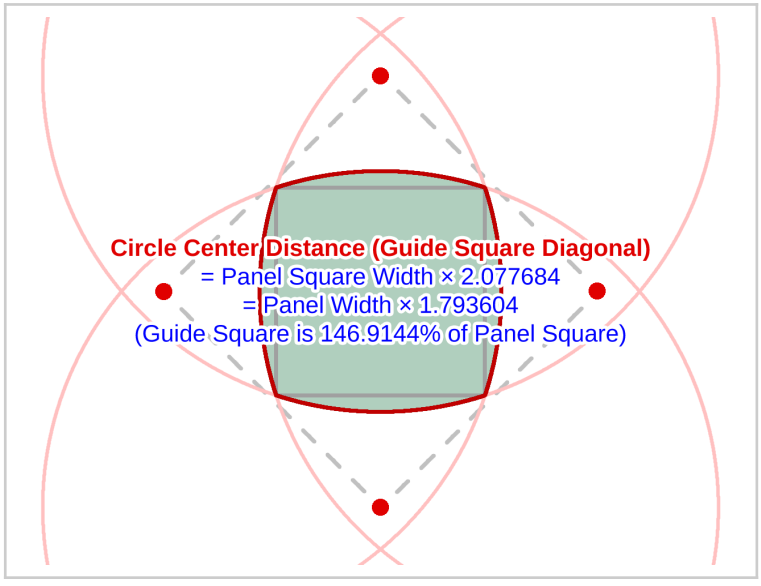
This section describes the math involved in drawing patterns to produce specified beanbag sizes, and creating the pattern sizing formulas. *(The numbers in tiny, right-justified typeface are my computer calculator's unrounded values which I display rounded to six places for brevity.)*

For this panel shape I chose curves that form a 126° angle 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 works better than curves that are slightly steeper and slightly shallower than this one, including the curve that forms a 120° angle at the vertices (which is the mathematically correct angle).

A square's corners are 90°, so my angle adds 36°, which means my arcs intersect the edges at 18°. 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 square, whose corners are the circle centers for the arcs that form the circular square:

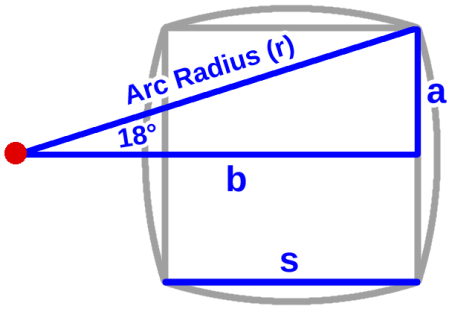
$$\textbf{Arc Radius} = \frac{0.5\,s}{\sin 18^\circ} = \frac{0.5\,s}{0.309017} \approx \mathbf{1.618034}s \quad \text{(s = inner square side length)}$$





Calculating the distance between the circle centers (Guide Square's Diagonal) involves solving a right triangle as shown below. The arc radius is the hypotenuse, side *a* is half of the square's side length, and I

need to solve for side *b*. After that, I can subtract the square's side length to get the portion of *b* that extends beyond the square, and add that back to the value of *b* to get the total distance.



$r \approx 1.618034s$ (calculated earlier)

$a = 0.5s$

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

$b = \dfrac{0.5\,s}{0.324920}$ or $\sqrt{(1.618034\,s)^2 - (0.5\,s)^2} \approx 1.538842s$

Guide Square Circumradius (center to corner) ≈ 1.538842*s* – 0.5*s* ≈ **1.038842*s***

Guide Square Diagonal (distance between circle centers) ≈ 2(1.038842*s*) **≈ 2.077684*s***

The width/height of the panel, which I use in the calculation of the other aspects of the panel design (as it is simply one fourth of the desired ball circumference) is the width of the square plus 2 × sagitta (height of the apex of the curve above the square's edge). The formula for the sagitta is the following (*r* = arc radius, *s* = square side length, or, in this context, the chord). Note that it is simply the radius minus side *b* from above.

Sagitta = $r - \dfrac{0.5\,s}{\tan 18°} = r - \sqrt{r^2 - (0.5\,s)^2} \approx 1.618034s - 1.538842s$ **≈ 0.079192*s***

Circular Square Pattern Width/Height, *w* ≈ *s* + 2(0.079192*s*) **≈ 1.158384*s***

Once I have the panel width expressed as a ratio of a unit square, I can express the arc radius and circle center distance in terms of it.

Inner Square Side Length (in terms of the pattern width) ≈ $\dfrac{1}{1.158384}w$ **≈ 0.863271*w***

Distance between Circle Centers (guide square diagonal) ≈ (2.077684*s*)(0.863271)
≈ 1.793604*w*

Guide Square Side Length (used for locating second pair of circle centers with a compass)
= $\dfrac{Diagonal}{\sqrt{2}} \approx \dfrac{1.793604}{1.414214}$ **≈ 1.268270*w***

Arc Radius ≈ (1.618034*s*)(0.863271) **≈ 1.396802*w***

Cutting pattern adjustment

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

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How I Developed This Design

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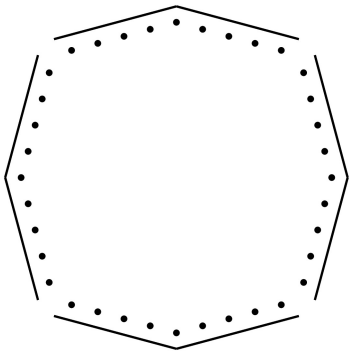
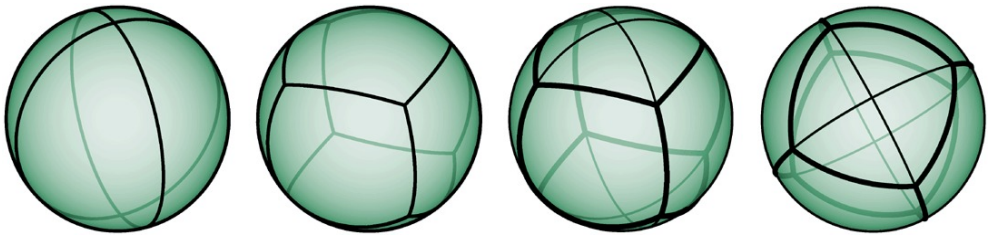
Original pattern design



I developed the original version of this design in August, 2012, a few days after the octahedron. I got the idea from the same website by Peter Billam (http://web.archive.org/web/20231105094249/https://pjb.com.au/jug/leatherballs.html). I had made a standard six-panel cubic beanbag years before as a novelty, but I had little interest in making another or in including it in these instructions. The idea of a spherical cube seemed worth trying, however.

Billam's cube pattern, along with the octahedron, dodecahedron, and icosahedron, uses angled bulges for the panel shape, as shown on the right. Angled bulges are simpler than curves, but will create new, and non-flat, vertices in the middles of the edges and produce an angular shape[3]. I wanted to use curves.

My original panel shape had a curve based on the 4-panel orange peel ball design (this was when I was still using a circular arc for that design) since the two designs are closely related. As shown below, the cube is conceptually the same as the 4-panel orange peel ball around the equator, with the four panel tips at each pole exchanged for a single panel that matches the equatorial portions. It turned out so well that I considered it to be as worthwhile a design as any of the other low panel-count designs and so I wrote out the formal instructions for it.



Relationship between the four-panel orange peel design and the spherical cube

When I received feedback via Reddit in February, 2015 about my octahedron panels being too steeply curved and, years later in May, 2020 when I found motivation to do something about it, I rethought all my panel designs. I decided that while the orange peel curve worked pretty well, it did pull the vertices inward a bit too much and bulged the edges outward too far in relation to the bag's overall profile.

Discovering the vertex-angle-sum design principle

Back in 2013 or so I had read an article on spherical geometry[4] 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 calculate the radius of the arc that will form a specified angle to a polygon edge. 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.

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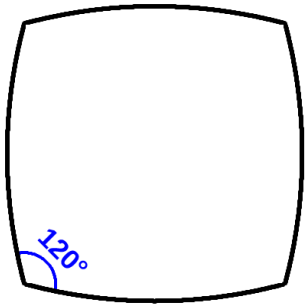
3 I made a beanbag using Billam's pattern and a stiff fabric in March, 2022 and it confirmed my assumptions. The vertices formed flat, triangular faces with the corners at the middles of the edges, at which point there were abrupt angles that felt like blunt spikes on the ball.

4 http://euler.slu.edu/escher/index.php/Spherical_Geometry

In the case of the cube, which has three corners at each vertex, the corners must be 120°. Peter Billam was evidently aware of this principle, because all of his designs' panel bulges, it turns out, create 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.



New edge-arc experiments for the Second Edition

My orange peel curve produces corners that are 129.791°. I tried a 120° curve and it did not work as well as I wanted, so I experimented with steeper curves while staying under the orange peel curve. For a full explanation of the mathematics of designing arcs that meet at specific angles, read the "Curved-Edge Faces" section of Chapter 5. I also discuss ways to deal with the fact that a circular arc that forms the correct angle does not necessarily bulge outward enough to form a good bag shape, and how to recognize the shape characteristics of a beanbag with too shallow or too steep a curvature.

Marylis Ramos, who created the best and most precise-looking juggling bag patterns I have seen[5], has a pattern for a cube which uses arcs producing 115° angles (I determined this by trying different arcs until one matched a magnified view of her pattern in Photoshop – see the illustration below). Though I was pretty sure an angle of less than 120° could not produce a good shape, I figured she must have had a reason to choose that curve and so I had better try it and see what happened. The result, as I expected, had vertices that were too prominent. I don't know why Ramos chose such a shallow curve.

I made two cubes (with two different fabrics) with 120° corners. Both still had vertices that were too prominent. I then tried a curve that put the circle centers the distance of the starting square's diagonal from its opposite side, that is, $\sqrt{(2)}s-s$ from the near side. That formed a 128.942° angle (just a little under the orange peel curve's angle), and that, like my orange peel curve, pulls the vertices of the cube inward a little more than I like (only very slightly). I next tried a curve that put the circle centers the distance of 2 side lengths minus the diagonal from the near side ($2s-\sqrt{(2)}s$). That formed a 124.893° angle. That worked pretty well and I almost decided to stick with that.

After a while I decided that the vertices of the 124.893° bag were still a little more prominent than I liked, so I decided to see how an angle halfway between that and the higher one would work. I made three cubes with a new fabric I had purchased which is tightly woven, thin, and non-stretch, and would best exhibit the cube's shape characteristics. I chose 127° for the middle angle and made one cube with that angle and the other two with the other two angles.

I had a hard time deciding which angle was best (the differences between the designs are very slight, as you might expect), but I finally chose the 127° angle. The larger angle is too close to the orange peel curve and that curve puckered in the vertices a little too much in the broken-in denim bag I made years ago. Though the new 128.942° bag felt more smoothly round than the 127° bag, I thought its edges were just a bit too steeply curved into the vertices. The 124.893° clearly had more prominent vertices.

5 "Sewing Patterns for Jugglers" Orange Segment Series and Polyhedra Series.

Adjusting the curvature to work better with stiff leather

Almost two years later, in February, 2022, I began to wonder if the curvature of my cube might be a bit too much after all, especially for a stiff leather. I think my reasoning was that a cube has 270° vertices and my design has 7° surplus angle at each face's corner, while an octahedron has only 240° vertices but my design has 6° surplus. It seemed to me that a wider starting vertex should not need more surplus angle to form a good sphere. Maybe 126° curves would be better. (I decided to trust my initial impression that the ~125° curve was not quite enough.)

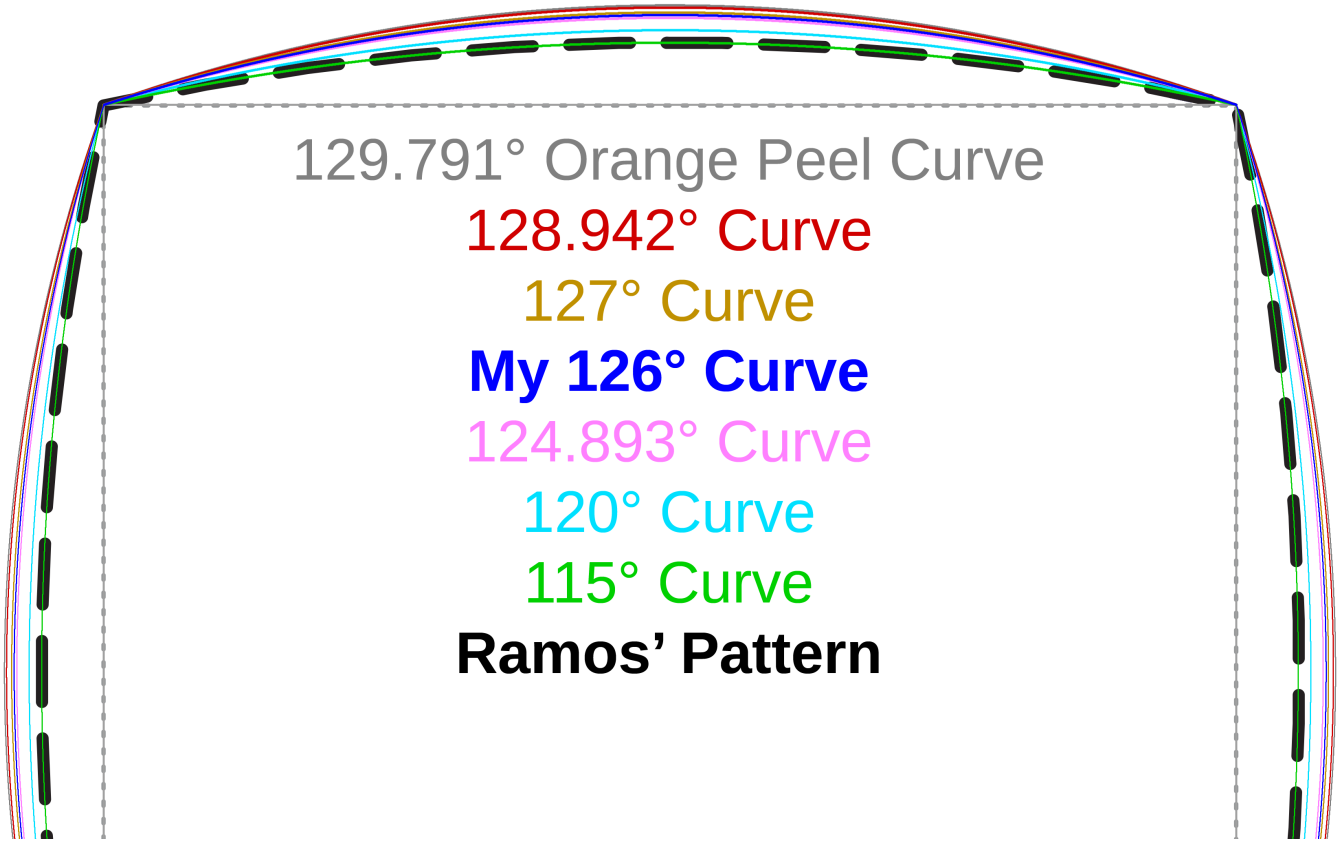
So I made a spherical cube with marine vinyl (which simulates stiff leather pretty well). I made it without seam allowances, with the panels edge to edge, and stitched it with a single-needle baseball stitch. The curvature did seem to be slightly too much, but it was hard to tell for sure. I made a second marine vinyl ball with a 126° curve angle to see if that improved the shape. The difference was hard to perceive, but in general the 126° curve angle did produce a slightly better shape. The 127° ball had faces that bent downward too sharply at the corners, while the 126° ball had more smoothly rounded faces that curved gently down into the corners. The difference was most apparent when I looked at the diagonal profile (the one shown in my third photo at the beginning of this chapter) with seams on the sides and faces on the top and bottom. The 127° ball had a more oval profile.

I then refilled and examined a felt ball I had made last February to test how my design responded to light, stretchy fabric. It seemed to exhibit just a hint of a similar flaw. Some of the seams had a tiny bit too steep a curvature so that their ends did not quite meet the circular contour of the ball, but ended inside that contour. The 127° curve seemed to be pulling the corners in just a little too much, but it was hard to see. I made a new felt ball and a matching 126° version. They both made excellent spheres, but the 126° version did seem to have a more consistently circular profile. I also made balls with my design testing fabric, but they were too similar to differentiate consistently.

After making four marine vinyl balls, the two additional felt balls, and the two design testing fabric balls, I was less certain than I had been that the curve change was beneficial. But I spent a couple days examining the balls and doing blind comparisons between the two designs and in the end, mainly based on the marine vinyl balls, I decided that the change was a slight improvement, but so slight as to be relevant only to those with a bad case of perfectionism. But this project helped relieve boredom for a couple weeks. So I edited my diagrams and patterns and adjusted the values in the math sections to reflect the change. I did not bother making a new corduroy ball or taking new photos or measurements. There is not enough difference to see or to be measurable.

Update from September, 2024: Through designing the 12-panel Simplified Volleyball/Cube, I have further confirmation that this curve is as steep as needed. That design is based on the cube, but each panel is divided in half with a curved seam between the halves. This makes it much rounder. I began with the regular cube's curve, which was almost perfect, and then increased it to 128°. The resulting seams are a little too steep when used with corduroy, and almost too steep with my design testing fabric. I think the lower roundness of the regular cube needs a slightly shallower curve to match, but the difference is very small anyway.

The illustration below is an overlay of all the curves over Ramos' pattern (the black dashed pattern). The side curves use thinner lines to aid in distinguishing them.



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