The Complete Homemade Juggling Beanbag Guide

12-Panel Spherical Dodecahedron 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.

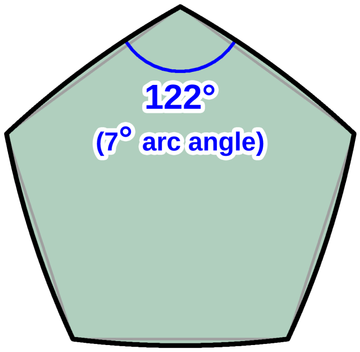
If this guide is useful to you, please **consider donating at my website** linked on the left. I am not monetizing the guide, and I am in need of income.

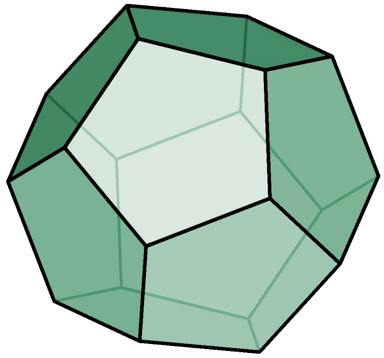
My website also provides blank **color arrangement diagrams** for experimenting with new arrangements in an image editor.

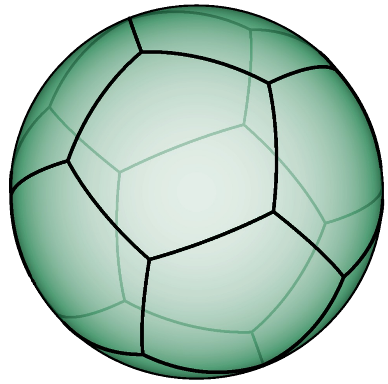
1 Icon from https://freesvg.org/vector-illustration-of-external-link-icon

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.

12-PANEL SPHERICAL DODECAHEDRON INSTRUCTIONS







My original, straight-edged, denim bag with the "Double Helix" color arrangement

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Design Notes

This design looks and feels **wonderfully spherical and uniform** compared to the designs of eight or fewer panels, but is more tedious and difficult to make because of the more complicated panel structure. It also has an advantage in the number and complexity of color arrangements that are possible.

For the Second Edition of this guide I was able to design **curved edges for the pentagonal panels** of the dodecahedron, making the bag even **more smoothly spherical**. See the “How I Developed This Design” section for more discussion. I provide patterns and drawing instructions for both the circular pentagon and the true pentagon, so that you can choose the simpler version if you wish, or make a cardboard model. The dodecahedron gains only a minor benefit by the addition of curved edges. It is still very round without the curves, especially with a soft, flexible fabric.

Supplies

- **For the templates**
  - Cardboard or Template Plastic, Scissors or X-Acto Knife, Glue Stick or Double-Sided Adhesive Tape (to attach the pattern to the template material). **For drawing the pattern by hand:** Paper, Protractor, Compass (for the circular panel shape), 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

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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 followed by pre-calculated pattern measurements and instructions for drawing the circular and straight-edged pentagons. Click the hyperlinks or look to the Chapter Index to locate those sections.

Color Arrangements

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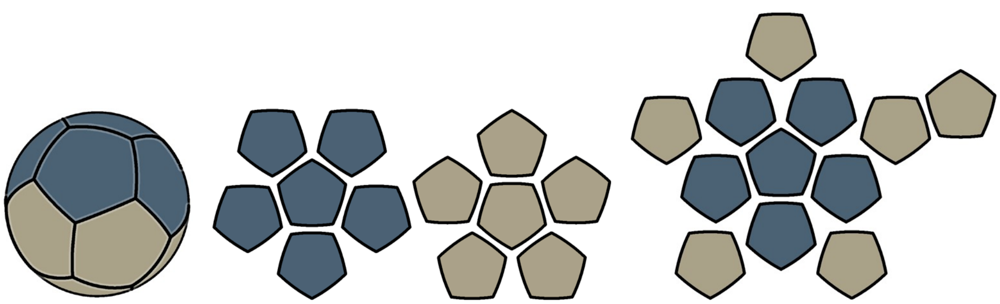
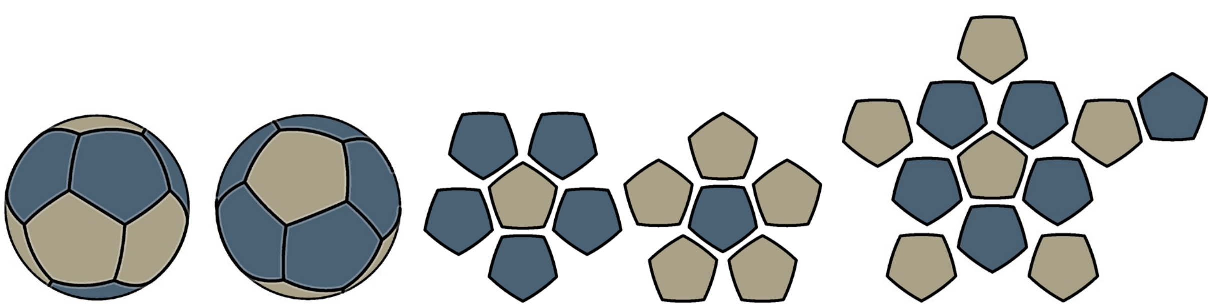
Following are seventeen color arrangement ideas of which eleven are mine and six are from *How to Make Leather Juggling Balls*[3] by Peter Billam (the latter are the ones in quotes with the British spelling of "colour"). The arrangements are grouped according to the number of colors they contain. I include **two different assembly layout diagrams** for each arrangement: the one for my **dual-hemisphere assembly method** (create two separate hemispheres and then sew them together around the equator) and a more **general purpose layout** in case you don't care for my method.

To help me design the more complicated of my arrangements and create the diagrams, I stuck colored thumbtacks into each panel of a single-color beanbag. This worked very well and I highly recommend it if you want to have some fun playing around with color arrangements. **I also provide printable blank color arrangement diagrams** for the ball views and the assembly layouts after the printable patterns. Look at the chapter index to locate them.

2 colors

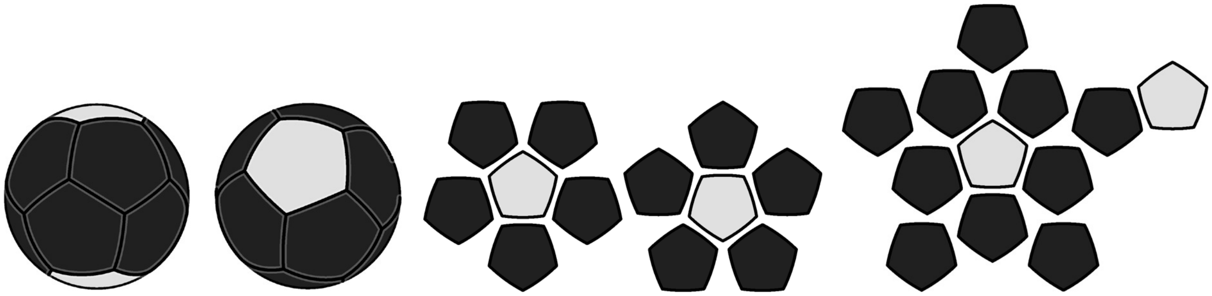


#1: Hemispheres. Each color covering an entire hemisphere.

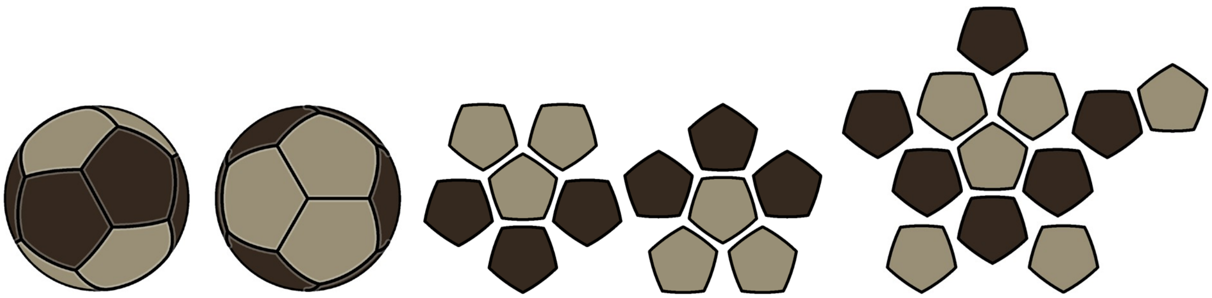


#2: Alternating Concentric Rings. "Five-fold rotational symmetry arises with one face of colour A at the top surrounded by five faces of colour B, and one face of colour B at the bottom surrounded by five faces of colour A."

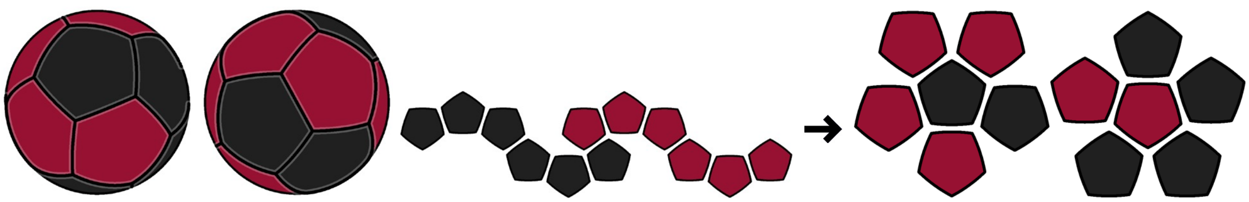
3 http://web.archive.org/web/20231105094249/https://pjb.com.au/jug/leatherballs.html



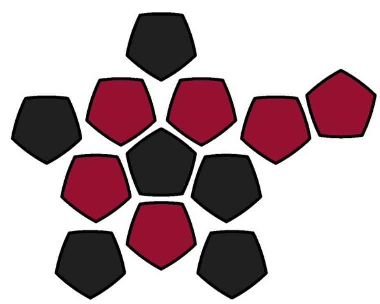
#3: Billiard Ball. Color A on two opposite panels with a double ring of color B between them.



#4: Undulating Belt. “Three-fold rotational symmetry arises with a patch of three faces of colour A at the top, a patch of three faces of colour A at the bottom, and a belt of six faces of colour B around the equator.”

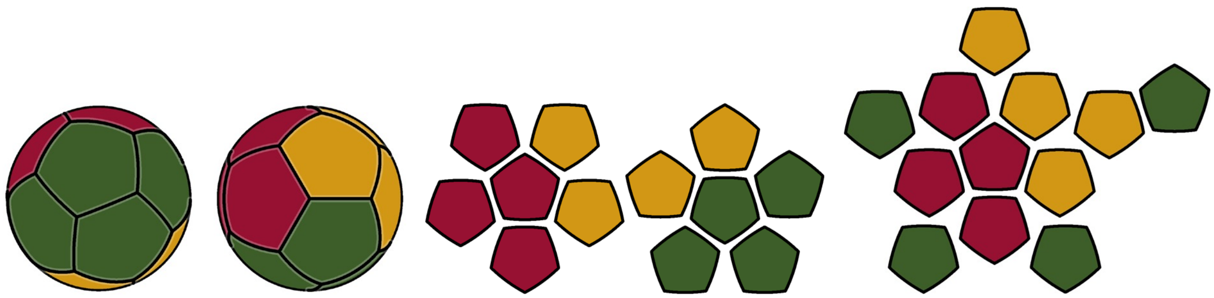


#5: Double Helix. “Two intertwining spirals [or serpentine curves, depending on how you look at them] of six faces can give a pattern with chirality, either left-handed or right-handed. This can be derived from the four-colour pattern [“Four-Color Patchwork Ball”] by pairing the four colours into two groups of two, and so the four-colour patterns also have chirality, though this is not obvious at first glance.”

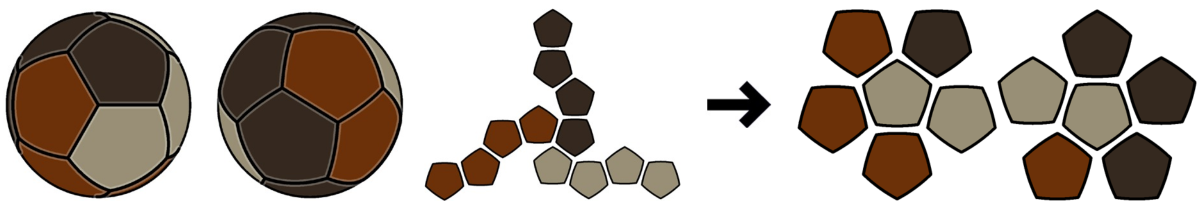


If you lay the panels out as shown above with the fronts facing up, you will get clockwise helices on the finished bag as shown in the illustrations. If you lay them out with the backs facing up, you will get the reverse curves, because that effectively flips the layout to its mirror image.

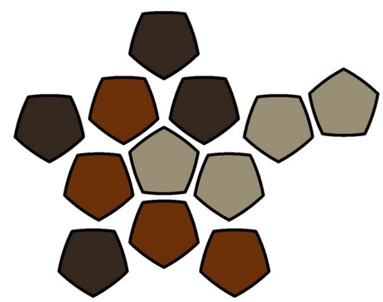
3 colors

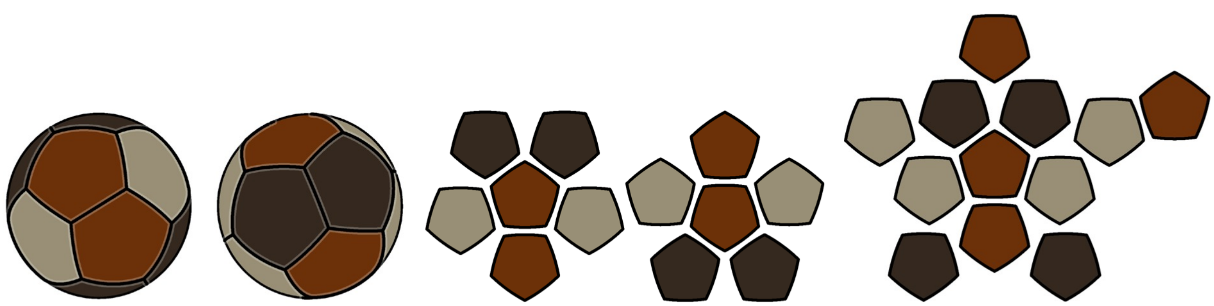


#6: Three Patches. Each color on a diamond-shaped patch of four panels.

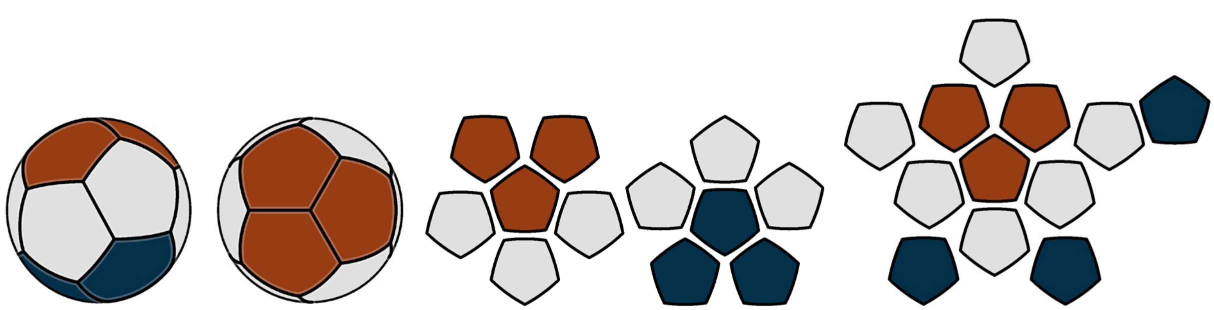


#7: Triple Serpentine. Each color on a serpentine row of four panels that starts and ends on opposite sides of the ball. If you lay the panels out as shown in the diagrams with the fronts facing up, you will get S-curves on the finished bag. If you lay them out with the backs facing up, you will get "2"-curves, because that effectively flips the layout to its mirror image.

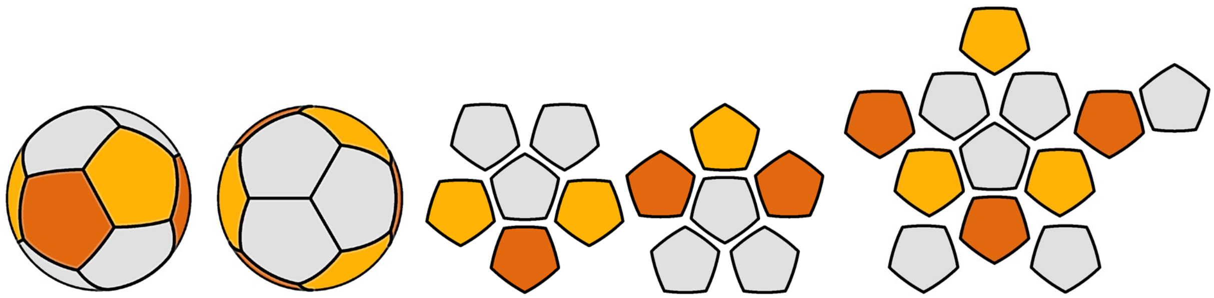




#8: Symmetrical Pairs. "Three separate two-fold reflectional symmetries arise if each colour is arranged in two opposite patches of two faces each."

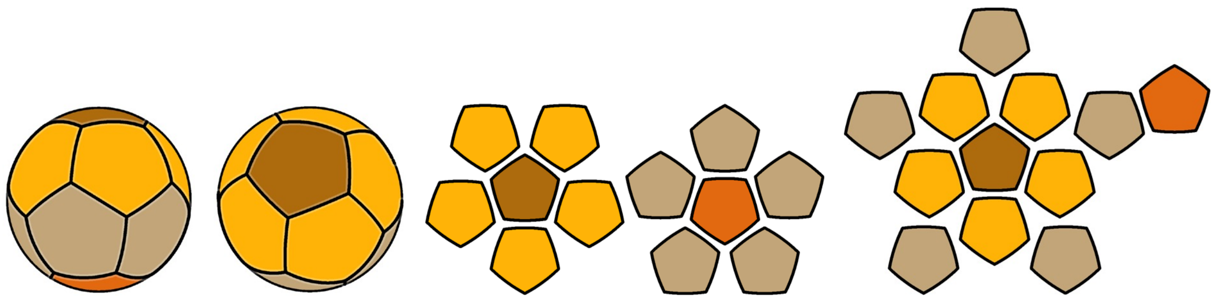


#9: Undulating Belt with Dual Caps. Same as the 2-color Undulating Belt arrangement, but each cap of three panels is a unique color.

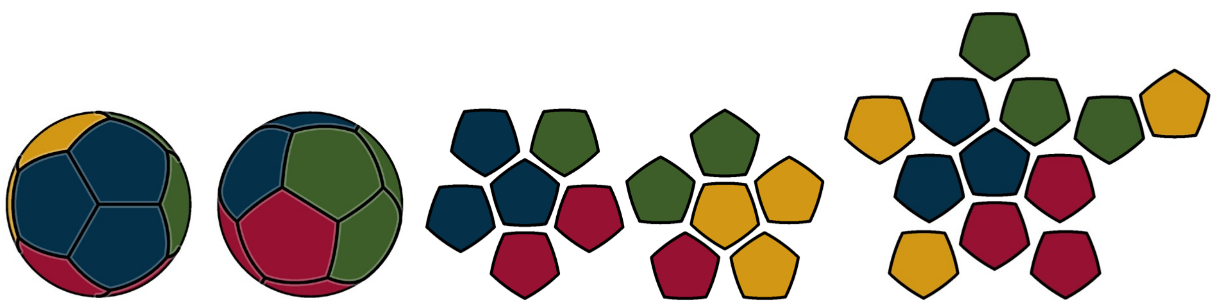


#10: Bi-Color Undulating Belt. Use a neutral color for the 3-panel patches at the top and bottom and an alternating pattern of two bold colors for the 6-panel belt around the middle.

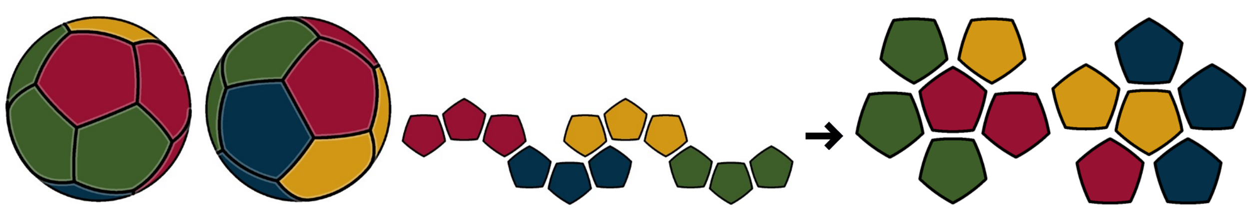
4 colors



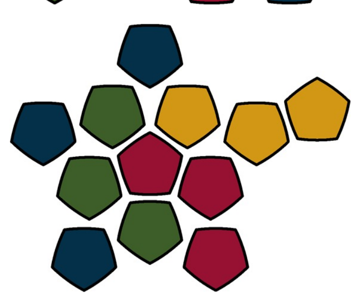
#11: Concentric Rings. Based on the 2-color Alternating Concentric Rings arrangement. One face of color A at the top surrounded by five faces of color B, and one face of color C at the bottom surrounded by five faces of color D. Each hemisphere can be a different theme, if you like, such as the Caffè Mocha and Mint on the right.



#12: Four Patches. Each color on a patch of three panels that share a corner.

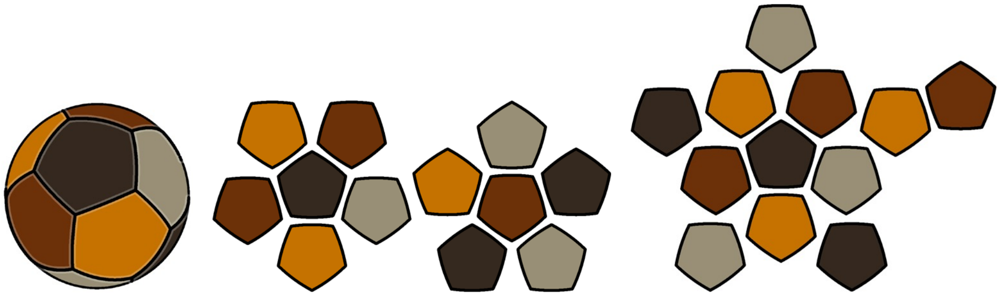


#13: Double Helix (4-color variation). Each color on a row of three panels. By using the two-color Double Helix arrangement to form this arrangement, you will get a pattern as follows (using abbreviations for the diagram colors): colors in the pairs B&Y and R&G curve into each other and each pair is opposite and

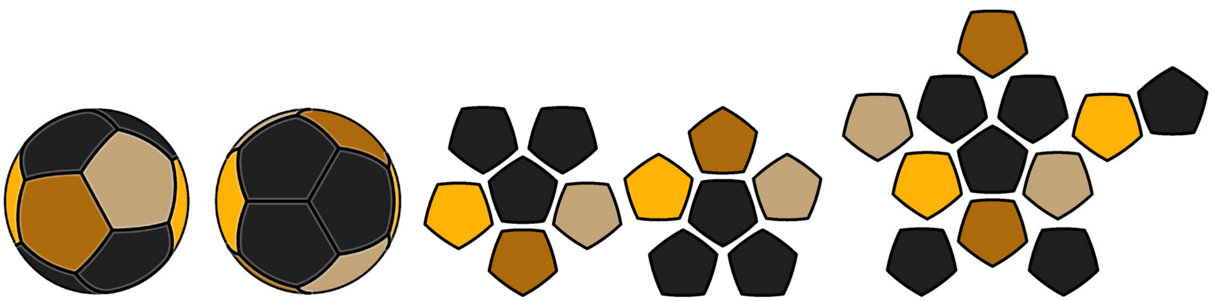


perpendicular to the other while colors in the pairs B&G and Y&R curve away from each other and these pairs are also opposite and perpendicular to each other.

There are other, random ways to position four 3-panel curves, but this method produces a balanced pattern. If you lay the panels out as shown above with the fronts facing up, you will get (bi-color) clockwise helices on the finished bag as shown in the illustrations. If you lay them out with the backs facing up, you will get the reverse curves, because that effectively flips the layout to its mirror image.

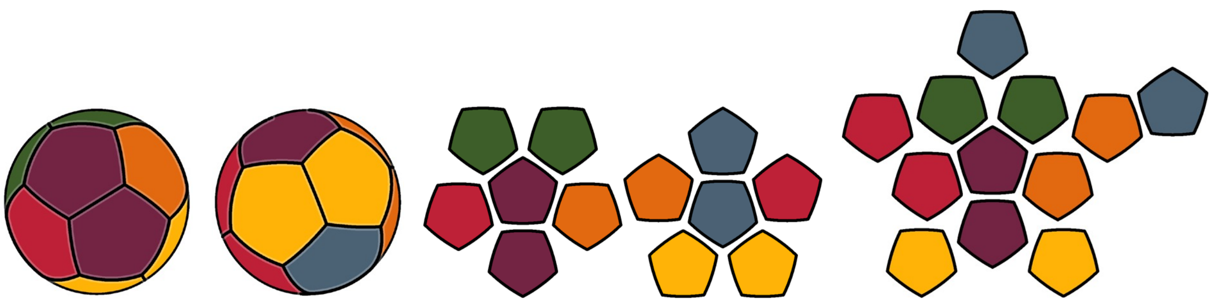


#14: Four-Color Patchwork Ball. "Four different colours arranged so that no side has a neighbour of the same colour. This would illustrate the Four-Colour theorem except that the Four-Colour theorem applies to maps on a plane rather than maps on a sphere; still, it refers to it. The four-colour patterns have chirality, though it is not obvious at first glance; it can be seen by pairing the four colours into two groups of two." This is the arrangement I used for my corduroy ball shown at the beginning of the chapter.

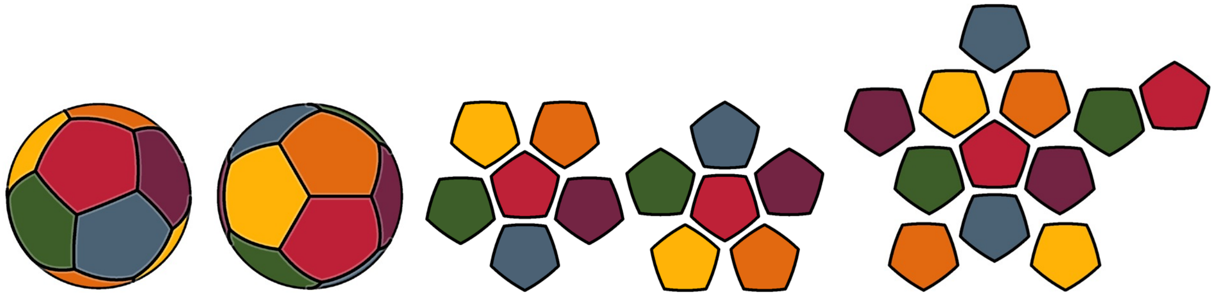


#15: Tri-Color Undulating Belt. Use a neutral color for the 3-panel patches at the top and bottom and a repeating pattern of three bold colors for the 6-panel belt around the middle (each belt color will be on a pair of opposite panels).

6 colors



#16: Patchwork Pairs. Same as the Symmetrical Pairs arrangement, but each pair is a unique color.



#17: Six-Color Patchwork Ball. "The two faces of each colour are placed opposite each other, and whichever angle the ball is viewed from, all six colours are visible." I arranged the colors so the belt around the middle has a different theme (dark, cool colors), than the 3-panel patches at the poles (bright, hot colors).

Cutting Out the Templates

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To make an exterior type template, simply use scissors to cut along the pattern (or an X-Acto knife and steel ruler for the regular pentagon). If you want to make a stencil (interior) type, you will need to use an X-Acto knife. So if you are using a circular pentagon and lack the skill to cut curves with a knife, you can convert the curves into three or more straight cuts that approximate the curve.

If you use a thick marker to trace the patterns, remember to **stitch on the side of the pattern lines where the edges of the template were** (inside the lines for exterior templates, outside the lines for stencil or combo), so you don't change the size of the ball. If the marker soaks through the fabric you're using, however, you will need to stitch inside the patterns to hide the lines within the seams. In that case, when using stencil or combo templates, cut out the templates' interiors slightly outside the lines, shifting the edges outward by the width of the marker lines. Then the edges of the patterns they produce will be correctly positioned for stitching inside them. For combo templates, shift the outer edges by the same amount to maintain the same seam allowance.

I recommend keeping the inner part that you cut out of stencil or combo templates for use in drawing the front stitching patterns. Step 2 of the Assembly instructions explains why.

Making the Panels

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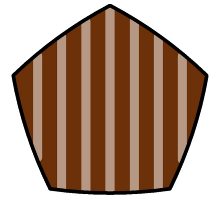
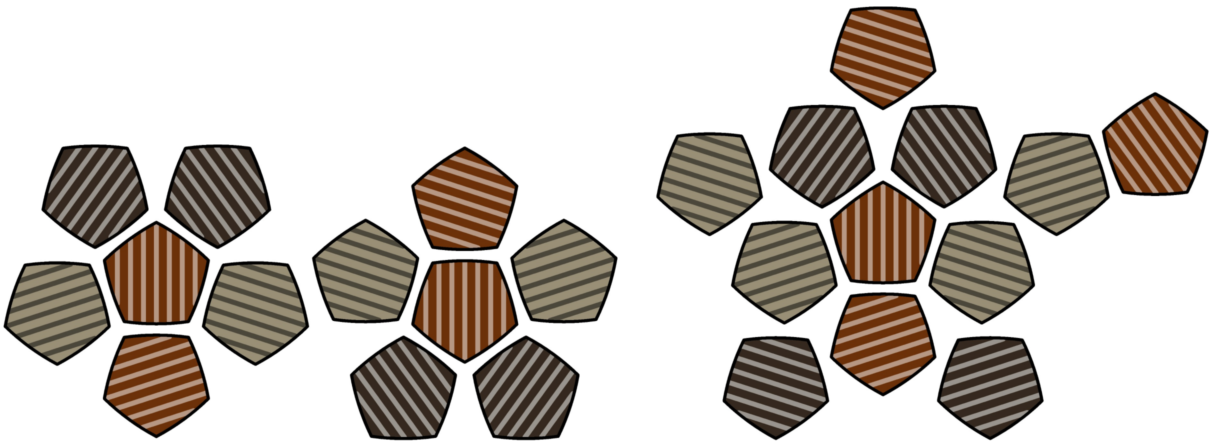
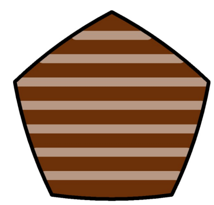
Depending on the type of template you're using (exterior or interior) and whether it is translucent or not, you must be careful which pattern, cutting or stitching, you trace first so that the **second template doesn't hide the lines of the first** and prevent you from aligning the two. **Do not necessarily use them in the sequence below**.

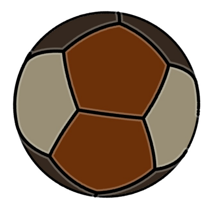
1. You will need 12 panels, and **you will be tracing the patterns onto the back of the fabric (the side that will be inside the bag)**. If you use a cutting template, first trace that. If you are using something like **corduroy or denim or other woven fabric**, t**here are various options for orienting the patterns in relation to the cords or grain of the fabric.**



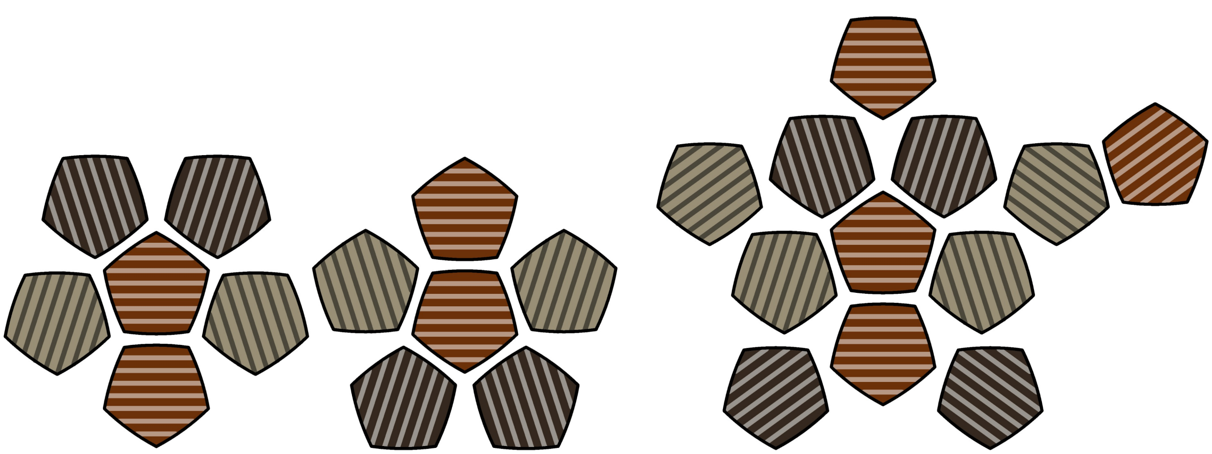
a. You can orient all the patterns with the lines running either from a side to the opposite corner (as I prefer, and is shown on the right) or parallel to a side, and then **randomize the panels' orientation** when you lay them out to assemble them so that the fabric's direction of stretch is balanced and **cords of corduroy or denim do not produce a visual pattern** that interferes with the color pattern. This is what I always did. **Below is a fairly regular, but random-looking arrangement you can use.** It only works properly with the vertical orientation shown. Pairs of opposing panels have parallel lines, but no adjacent panels have lines that run through the pair from end to end.







b. **A more straight-forward and balanced approach** is to again orient all the patterns on the fabric the same way, but then to lay them out as shown below, producing six pairs having parallel lines. The pairs are arranged like the 3-panel groups on a classic volleyball[4]. They are parallel to the opposite pair but perpendicular to the adjacent pairs. I recommend orienting the fabric lines parallel to an edge as shown on the right so that there are not continuous lines running through the pairs, which might interfere visually with the color arrangement. With color arrangements like the one illustrated here, though, you could orient all the patterns vertically as shown in option *a* to make the panel pairs more obvious, and more reminiscent of a volleyball.



4 Thanks to Uri Yurman for this idea for balancing the fabric's direction of stretch in the 30-panel structure, which I adapted to this structure.

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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I assemble this design by forming two separate hemispheres and then sewing them together. This gets all the panels joined to each other as soon as possible, and in a simple and clear manner, which reduces the risk of losing track of the arrangement during assembly. **If you prefer simply to attach all panels to a central, starting panel**, use that layout type from my color arrangements section instead of the one in Illustration A. You can then start with the stitching path I use for the first hemisphere (Illustrations A & B, or A_{ALT}), and continue from there to attach the rest of the panels. The remaining illustrations and some of the written instructions will not apply.

For the dual-hemisphere method I describe **two different approaches to sewing the hemispheres**: my original approach which uses 7-11 threads, and an alternate one based on my 32-panel assembly method that uses few as 3 threads. The alternative approach is much simpler at the cost of more duplicate stitching.

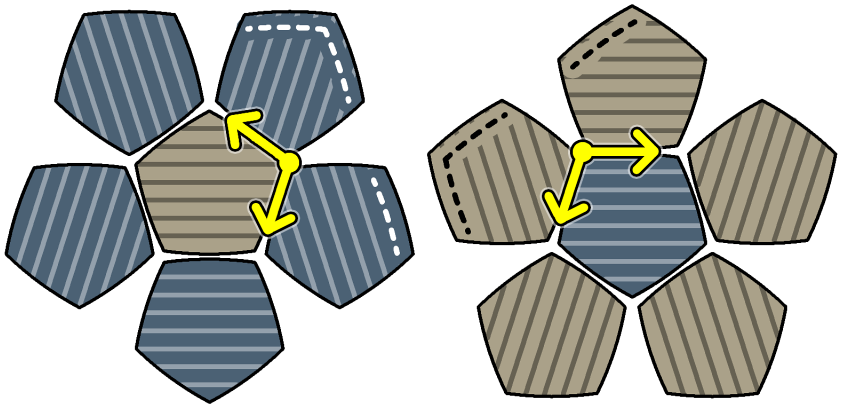
The **original method** is to sew only around the hub panels, beginning at the intersection in the center of the arrows in Illustration A, and then out that spoke seam, leaving the remaining four spoke seams open. Then each spoke seam of one hemisphere is sewn together using additional threads (the first is shown in Illustration B), and each thread is continued into the other hemisphere's spoke seam (Illustration C).

In the **alternative method** (Illustration A_{ALT}), the hub thread is used to sew out and back at each spoke seam, resulting in completed hemispheres. Attaching the hemispheres is then much simpler and easier. The duplicate stitches can be extra long (at least if you are using the backstitch), and so are not terribly tedious. For advice on crossing the spoke seam intersections as you proceed around the equator see the "Crossing seam intersections…" topic in the "Stitching Techniques" section of the **General Information and Techniques** chapter.

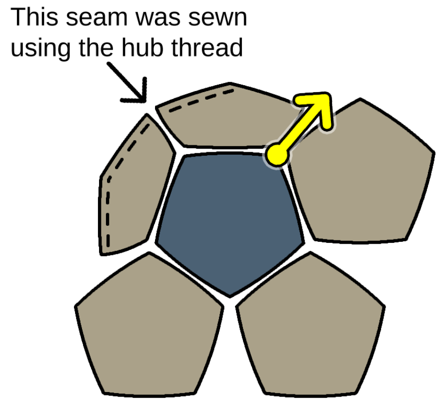
Finally, a new thread or threads are used to sew around the "equator" (Illustration D). You will be sewing up to three equatorial seams from the outside (indicated by the dashed lines).

With so many panels and seams, **it is easy to make a mistake** and misalign the panels. I also once accidentally joined four pentagons together at a vertex instead of three. Be careful of that. It may be helpful to make a cardboard dodecahedron with colored panels or labels to help keep track of what you are doing. Index cards, file folders, or something of similar thickness work well for this. Just make a regular pentagon template (rather than a circular one), cut several layers at a time to produce the panels faster, and tape them together.

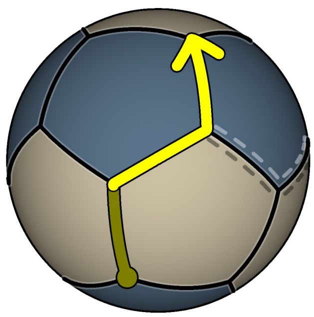
A **Sew around each hub panel starting between the panels with the front stitching patterns, then out the spoke seam.**



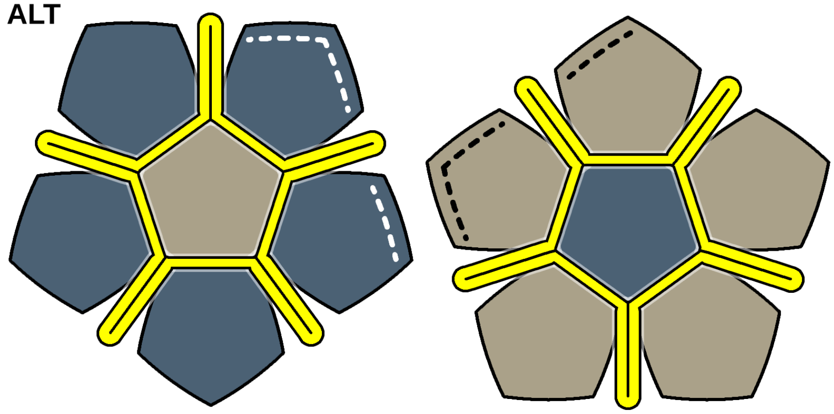
B **Sew a spoke seam adjacent to the front pattern.**



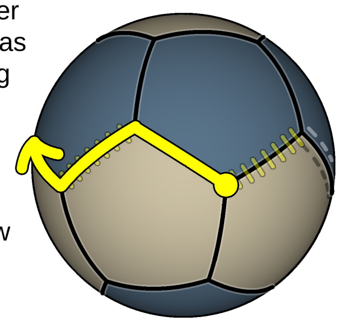
C **Continue into the other hemisphere.**



A ALT **Or, sew around the hub panels, but at each spoke seam sew out and back before continuing around. Skip B and C.**



D **After sewing all spoke seams, sew around the equator.** Unless you used the alternative method, every other equatorial seam was already sewn using the spoke threads (as shown by the faint yellow stitches). Restitch them or start a new thread between each one.



Note that in illustrations C and D the ball is still inside out and so the front stitching patterns (the dashed lines) won't actually be visible. I show them just for positional reference.

1. ***Illustration A:* Lay the panels out as shown and arrange them according to your color pattern.** Note that my illustrations and color arrangement diagrams assume that the fronts face upward (the orientation makes a difference in chiral color arrangements, and this is noted in their descriptions). The **hatching lines in Illustration A are a suggested method of balancing the fabric's direction of stretch** if you are using a woven fabric. With something like corduroy or denim or a striped fabric, it will also produce a balanced, symmetric appearance. Further explanation of this, and a more random-looking arrangement, is in the "Making the Panels" section.

2. Use the stitching template to **draw stitching lines on the *fronts*** of the six outer panel edges shown with dashed lines to form three seams in a row around the equator. My stitching pathway leaves these three seams 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 pair or two of edges.) 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 seams**, sketch them a millimeter or two nearer to the panel edges and stitch slightly inside them (toward the middle of the panels). **If you use a Stencil or Combo type template,** use the inner portion that you cut out of the template to draw these patterns, since the main template will cover the area near the edge.

   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. ***Illustration A (stitching):*** **Start with a center panel and sew a panel to each of its sides** beginning at the corner between the panels with the front stitching patterns and proceeding in either direction. (If you only marked one pair of edges, just start on either side of it.) **Sew the panels with their front faces together** so the bag will be inside out.

4. When you have attached all five panels and the thread has reached the starting point again, **sew the adjacent sides of the two outer panels together, connecting the two segments of the front stitching lines**, and then tie off the thread and trim it. You are done with this hemisphere for now. The spoke seams (the adjacent edges of the outer panels) will be sewn with threads that continue from the other hemisphere.

5. ***Illustration A_{ALT}:*** If you prefer to complete the hemispheres, which are then much easier and simpler to join together, at the cost of more duplicate stitching, **sew out and back at each spoke seam** as you proceed around the hub panel. If you are using the backstitch, you can make the duplicate stitches up to twice as long without causing the fabric to ripple as long as you're careful how tightly you pull them (if you pucker the fabric, wiggle it straight again). You may start at any point around the hub panel in this method, and you will be ignoring Illustrations **B** and **C**. Be sure to read the **Notes on joining the two hemispheres** before joining them, and then skip to Step 11 (Illustration D).

6. Construct the other hemisphere in the same way.

7. ***Illustration B (skip if following A_{ALT}):*** On either hemisphere, **sew a spoke seam** that is adjacent to the one that is already sewn, starting at the center panel and sewing outward. The next step continues this thread, so leave it hanging.

8. ***Illustration C (skip if following A_{ALT}):*** Now continue the thread into the other hemisphere by taking the branch toward the front stitching pattern, unless that branch *has* a front stitching pattern on it, in which case take the other branch. (From now on, always take that same branch at the intersections; this prevents the annoyance of the other hemisphere having one unsewn spoke seam at the end.) You will now **sew an "equatorial" seam**, which will **join the two hemispheres**.

Notes on joining the two hemispheres: Be careful when choosing which panel edges from each hemisphere to join together. The hemispheres must be aligned in such a way as to form your intended color pattern and to make the front stitching lines on each half meet each other. **Aligning the panel edges correctly can be somewhat confusing**. Remember that three panel corners always meet at each vertex of the bag. Joining the first couple of equatorial edges is **easier if you flip the hemispheres right side out** so the front faces of the panels are exposed and can be placed together.

9. ***(Skip if following A_{ALT})*** Now **continue up the other hemisphere's spoke seam**, ending at that hemisphere's center panel. Tie the thread and trim it. (Or, if you don't mind some redundant stitching, stitch across the hub seam to the next set of spoke seams, and sew back down to the first hemisphere. If you are using the backstitch, you can make the duplicate stitches up to twice as long without causing the fabric to ripple as long as you're careful how tightly you pull them. If you pucker the fabric, just wiggle it straight again.)

10. ***(Skip if following A_{ALT})*** **Repeat the previous three steps for each of the spoke seams**. Each new thread will sew three seams – one spoke seam on the starting hemisphere, one equatorial seam between the two, taking the same fork direction as the first thread, and one spoke seam on the second hemisphere, ending at the second hemisphere's center panel. Be sure you **don't accidentally stitch the seams with the front stitching patterns**.

11. ***Illustration D:*** **Start a thread at one end of open seams with the front stitching lines** (skipping the seam you already sewed) and **sew away from them around the equator** until you reach the other end of the front-stitched seams. If you are not following the **A_{ALT}** method, you will encounter two or three seams that are already sewn. You can either re-stitch them or tie off the thread and start a new one after those seams. Remember that if you use the backstitch you can make duplicate stitches up to twice as long.

    For **advice on crossing the spoke seam intersections** as you proceed around the equator see the "Crossing seam intersections…" topic in the "Stitching Techniques" section of the **General Information and Techniques** chapter.

    Tie the thread when you reach the other side of the front stitching pattern. (To aid in turning the bag right side out, especially if you did not mark all three pairs of seams, tie the thread off one seam prior to the front stitching lines, then either continue that thread or start a new one, and sew the front seams with that. Allowing some of the stitches prior to the open seams to loosen will help the panels to spread enough to fit the bag between them. You can then re-tighten them from the outside.)

12. **Sew a few starter stitches at one end of the final opening** 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**.

13. At this point, **consider ironing the seam allowances flat**; see the **General Information and Techniques** chapter under "Better Seams by Ironing".

14. **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**.

15. **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").

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Ready-to-Print Patterns

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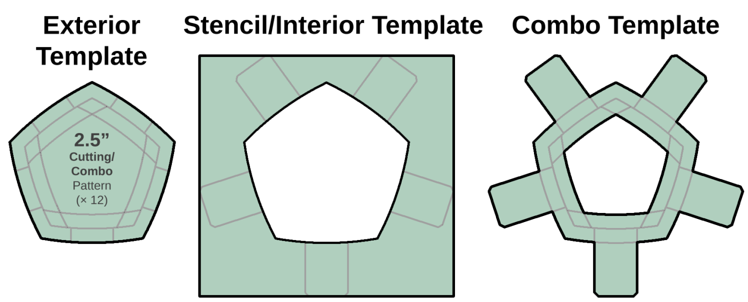
The pattern pages are 8.27″×11″ (210mm×279mm) to fit both "Letter" and "A4" sizes. ***Make sure the print is not being scaled to fit the printer margins*** *(select Default/None scaling/Actual size/Ignore printer margins). To verify correct sizing,* ***compare the centimeter grid to a ruler*** *and adjust 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 6.4% from the mathematical calculation to account for the inflation in size I observed in my corduroy bag. **If you use a dense/stiff or completely non-stretch fabric, I recommend enlarging the pattern to about 105% 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 gluing or taping 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 pattern is a hair under ¼″), and they include **tabs for the optional combo type template** (stitching pattern on the inside, cutting pattern on the outside, with the tabs to help you hold it down). Three tabs may be sufficient with a rigid template.

The examples on the right show the **three ways you can cut out the Cutting/Combo templates** (using the 8mm allowance). 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.

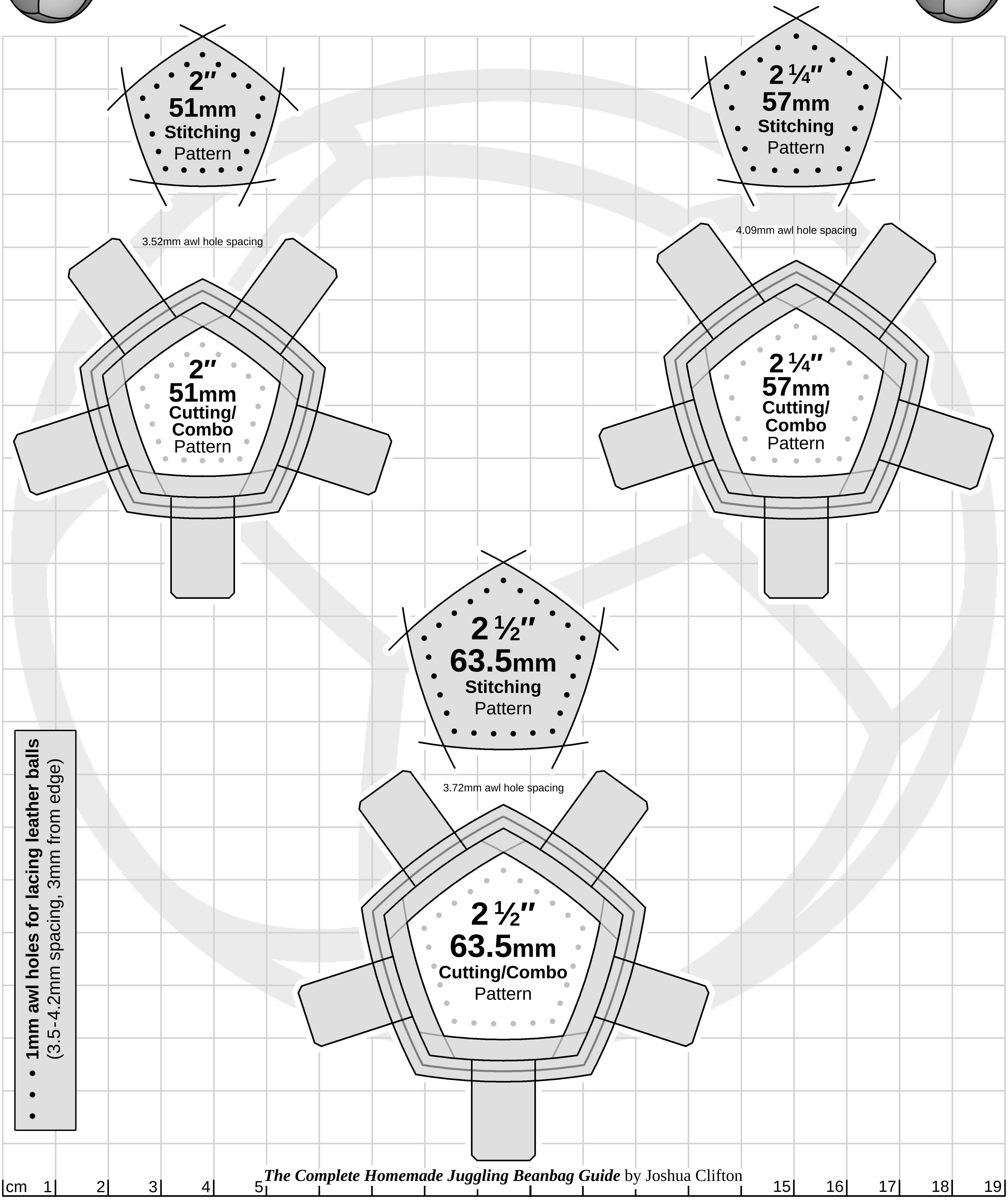
The table below provides the scaling for the ⅛″ increments between my ¼″ sizes. The centimeter grid can be used to verify correct scaling.

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%

If you cut out these patterns as straight-edged pentagons (from corner to corner), the resulting beanbag will be about 97.5% the size of the circular-edged version. So to produce the same size, scale the printout to 102.8%.

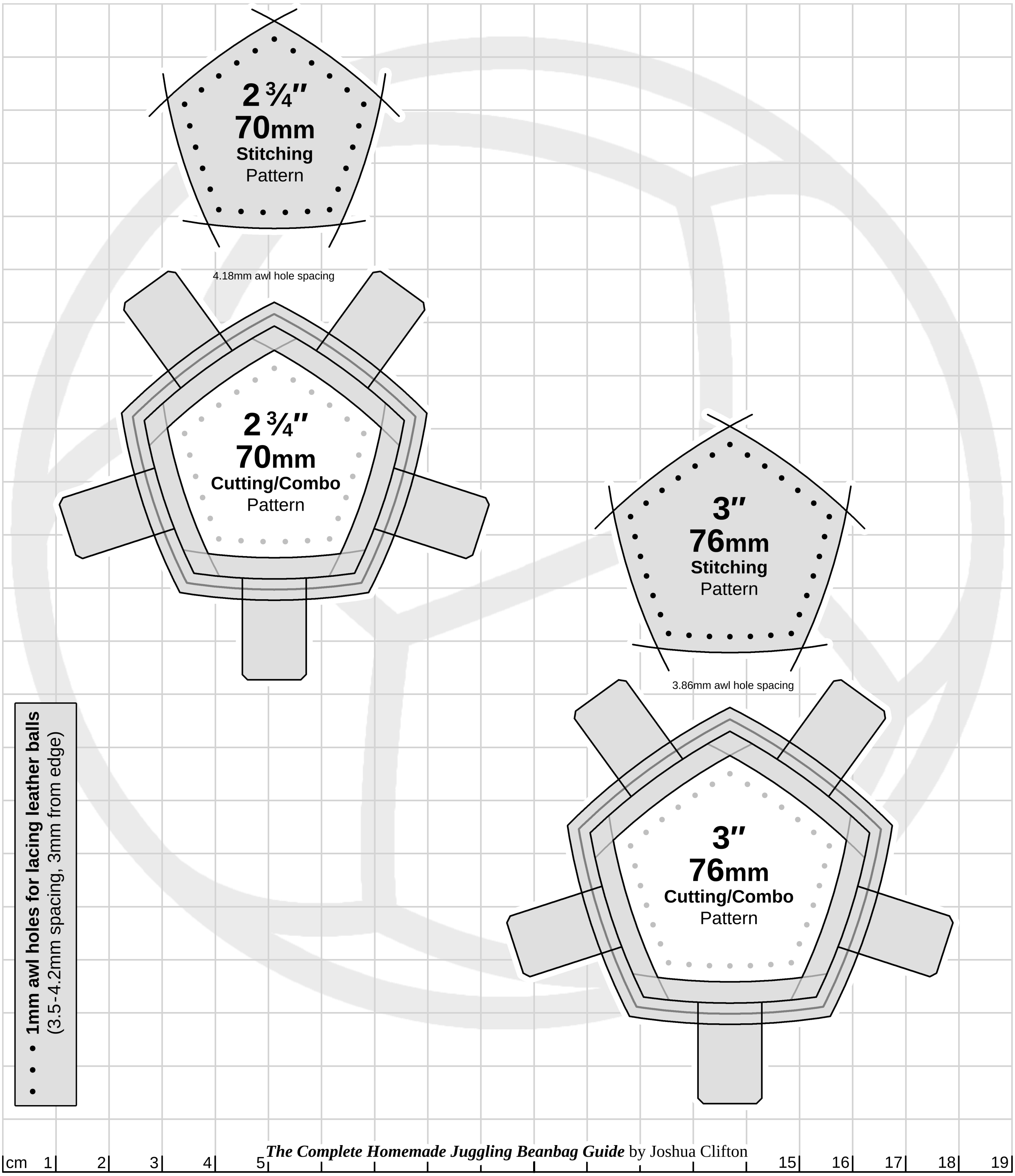
Dodecahedron (12 Panels)

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



Dodecahedron (12 Panels)

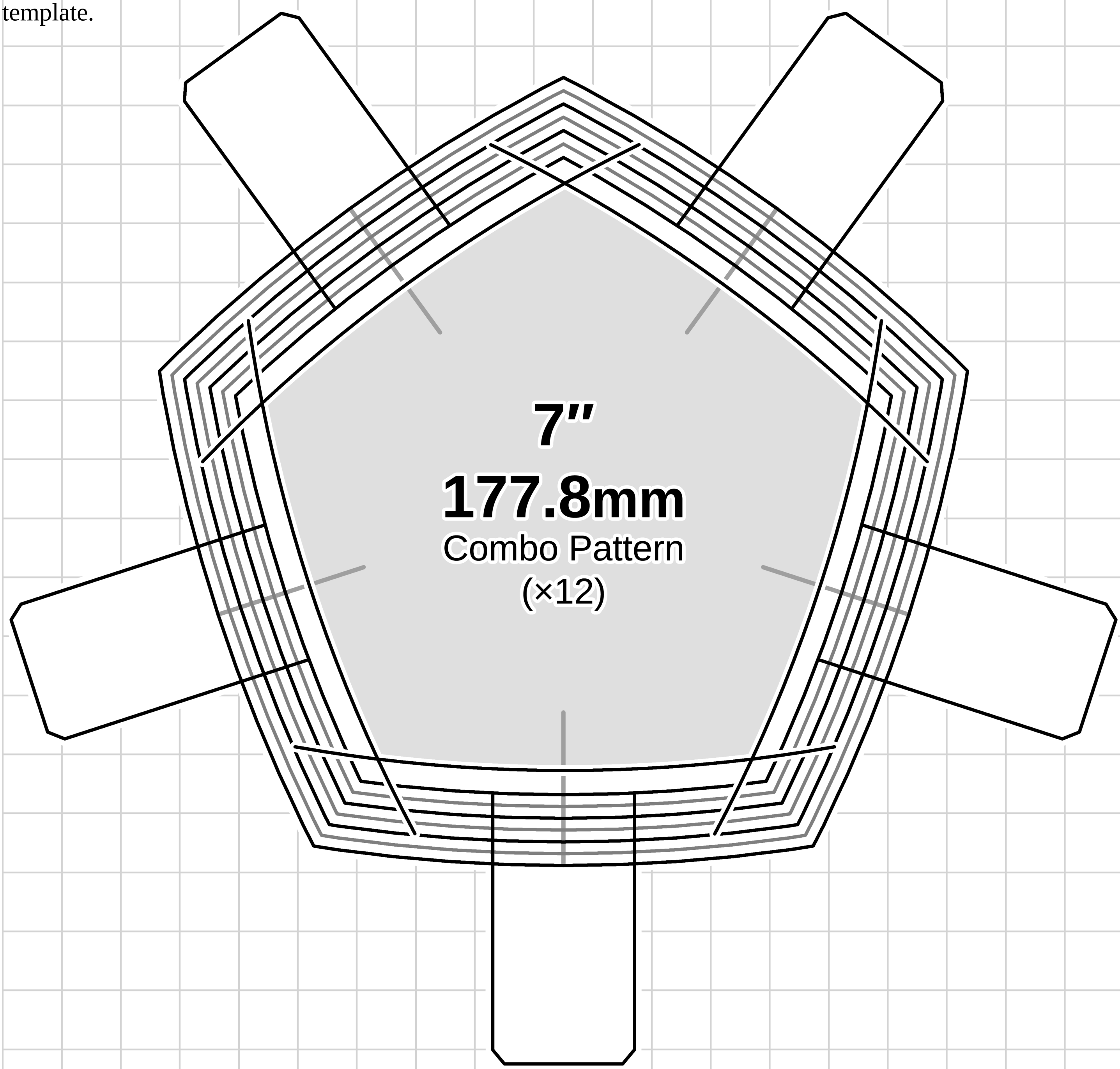
(Pattern sizes are adjusted for corduroy and do not account for gathered seams)



Dodecahedron (12 Panels)

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

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 (or cut out a combo 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.



Blank Color Arrangement Diagrams

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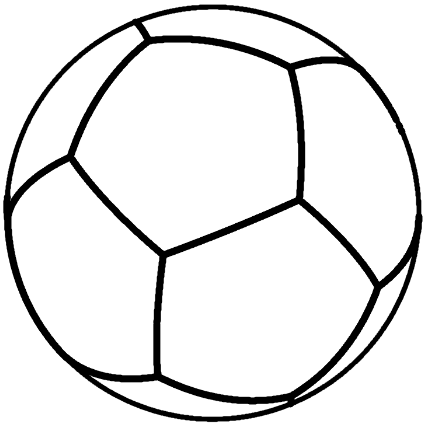
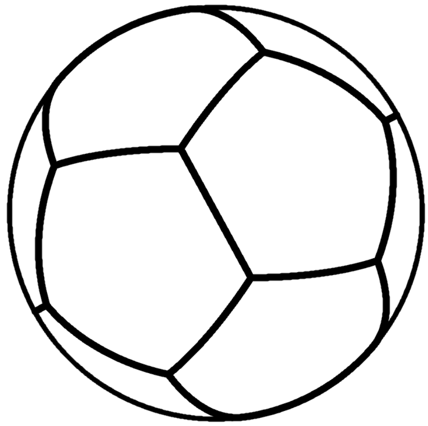
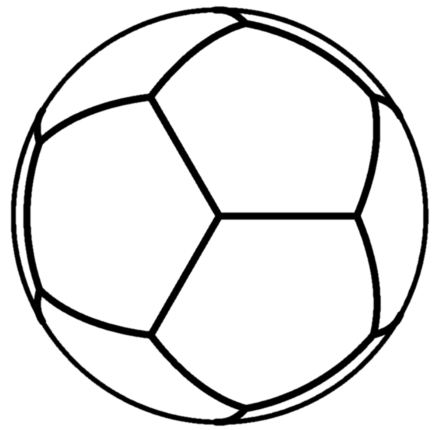
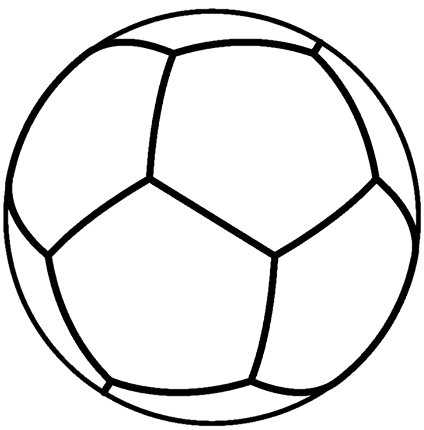
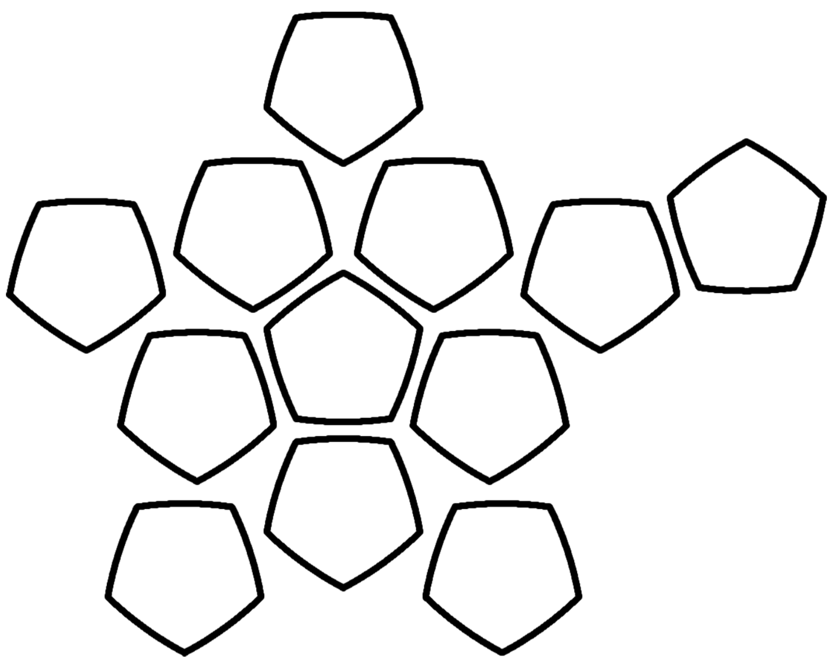
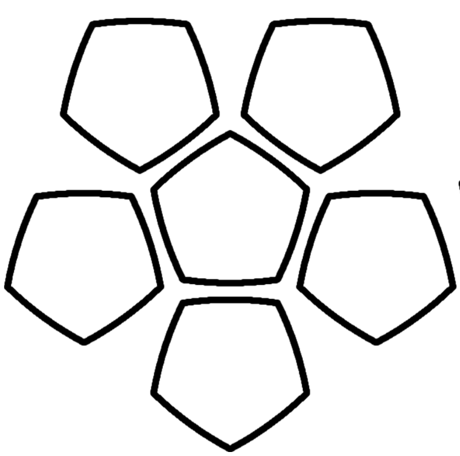
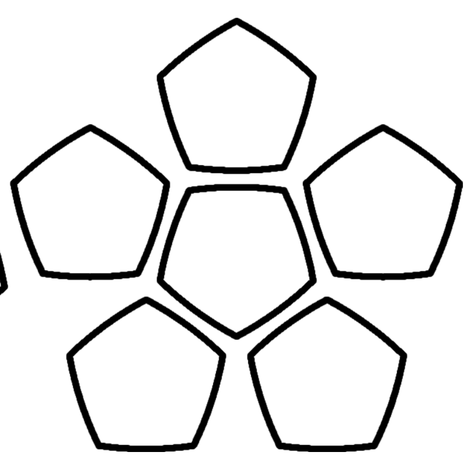
These are the ball and assembly layout diagrams I used for my color arrangement illustrations. You can use these to experiment with your own arrangements. I also offer PNG format diagrams for download on my website that you can use in an image editor. If they are unavailable, you can capture a screenshot of this page or export the image and then color it in an image editor. Or you can just print it and color it by hand.

Sizing Formulas for Drawing the Pattern

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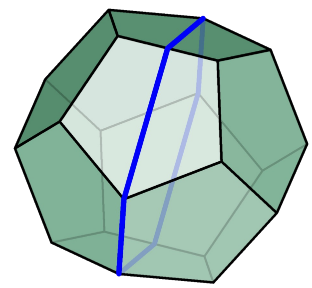
The next two sections each have a table of pre-calculated pattern measurements for all ⅛″ diameter increments from 1 ¾″ – 3″, along with drawing instructions. If you do not need to create a custom size, skip to those. I provide printable measuring tapes at the end of the **General Information and Techniques** 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 either by drawing a regular pentagon, or by drawing a much larger guide pentagon whose corners are the circle centers for the arcs that form a circular pentagon within it. The circumference of the bag is composed of 4 panel heights and 2 panel edge lengths as shown on the right.

To alter the size of the bag, you need the relationship between the pentagon's dimensions and the resulting bag circumference so you can draw the right pattern size for a desired bag size. To draw the panel shape manually you need the pentagon's side length, and to draw it in SketchUp using the polygon tool, which uses a defined circumradius, you need the pentagon's circumradius (center to corner). I provide the formulas that define those relationships below, and they are fully explained and illustrated in the "Mathematics" section of this chapter.

Adjusting for the influence of fabric attributes on beanbag size

The bag I made with thick corduroy was **4.34 – 8.52%** 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 **6.4%**. This makes my adjustment factor **1.064**.

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".

The bag I made with my design testing fabric which is fairly thin, stiff, tightly-woven, and non-stretch, was 1.18 – 3.46% larger, but that was just for analyzing the shape characteristics of the bag. Though I did not make a straight-edged dodecahedron with corduroy, the one I made with my design testing fabric inflated 0.97% less than the circular one with the same fabric. I am guessing the corduroy one would have the same difference in inflation, so I am assuming 5.5% in the straight-edged panel sizing table. (Just as a matter of record, my straight-edged denim bag from years ago was 1 – 4% larger.)

As I understand it, the bag size is affected by fabric attributes as follows. The folding of the fabric at the seams will cause thick, firm fabrics to significantly shrink the bag size unless the fabric has some stretch. Folding thin fabric doesn't consume as much of its size, but my design testing fabric, though fairly thin, has no stretch at all, and so ended up producing about the same size bag as the denim, which stretches a little. Corduroy is a softer, more loosely woven fabric than denim and flexes and compresses more easily, and so not as much of the panels' size is consumed by the folding. My denim and design testing fabric bags have very prominent seams while the corduroy bag has much more subtle seams.

Sizing formulas – circular pentagon

Below are the formulas to calculate the pattern construction elements (*Diameter* and *Circumference* refer to your target ball size). 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.**

- **Guide Pentagon Side Length = *Diameter* × 1.5089 ÷ 1.064**
  = *Circumference* × 0.4803 ÷ 1.064
- **Guide Pentagon Circumadius = *Diameter* × 1.2835 ÷ 1.064**
  = *Circumference* × 0.4086 ÷ 1.064
- **Arc Radius = *Guide Pent Side* × 1.0313**
  = *Guide Pent Circumradius* × 1.2124
- For double-checking: **Inner Pent = *Guide Pent* × 3.9781** (radius or side length)
  Panel Height = *Arc Radius* × 0.3825

Sizing formulas – regular/straight-edged pentagon

- **Regular Pentagon Side Length = *Diameter* × 0.3852 ÷ 1.055**
  = *Circumference* × 0.1226 ÷ 1.055
- **Regular Pentagon Circumadius = *Diameter* × 0.3277 ÷ 1.055**
  = *Circumference* × 0.1043 ÷ 1.055
- For double-checking: **Pentagon Height = *Side Length* × 1.5388**
  = *Circumradius* × 1.8090

Forming the circular pentagon from a regular pentagon

If you want to convert a pentagon into the circular pentagon shape by adding curved sides to it, here are the calculations (s = starting pent Side length, r_t = starting pent Circumradius):

- **Guide Pentagon is 397.81% the size of the Panel Pentagon**
- **Distance between opposite Pentagon Side and Circle Center = 4.0721s**
- **Arc (circle) Radius = 4.1028s = 4.8231r_t**
- **Guide Pent Side Length = 3.9781s**
- **Guide Pent Circumradius = 3.9781r_t**

How to Draw the Circular Pentagon

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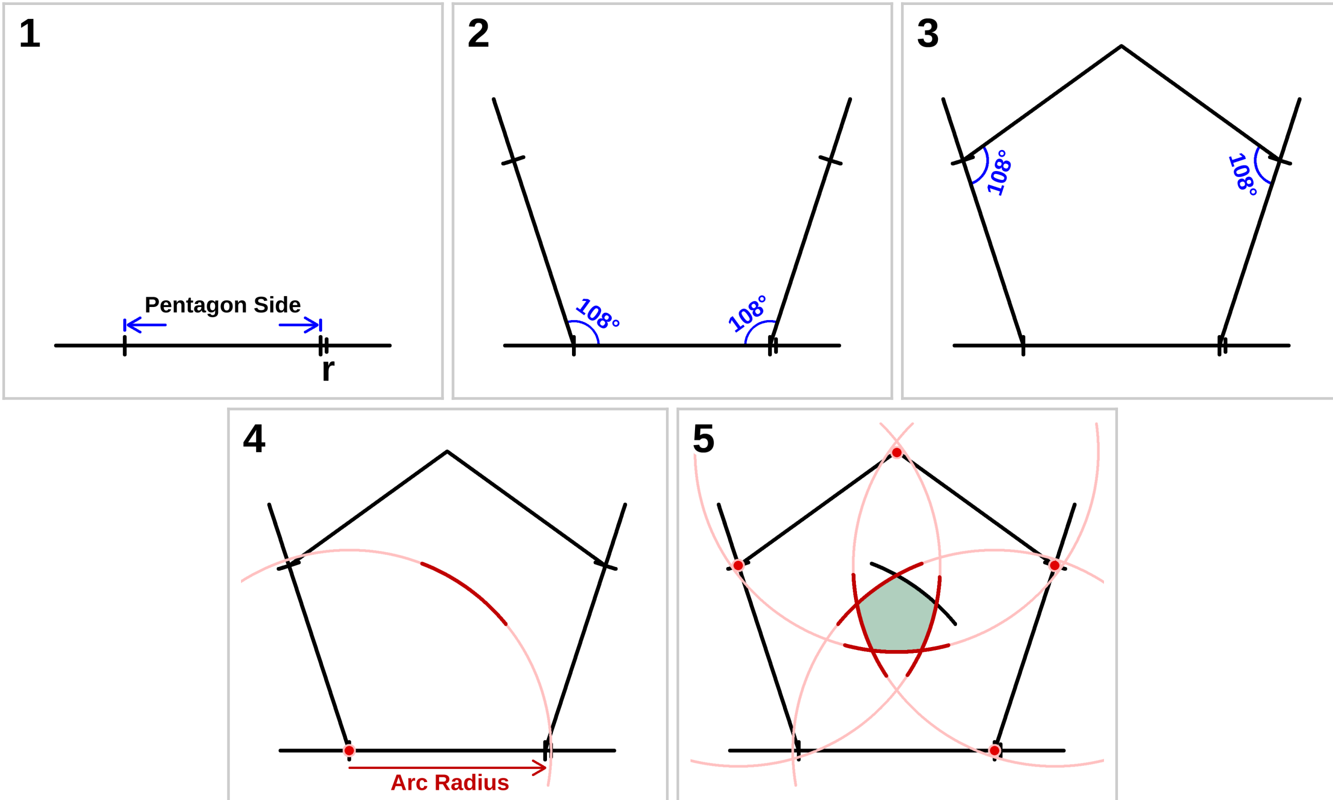
Following the pattern measurement table are manual and SketchUp directions for drawing the circular pentagon panel shape, and a table of pattern measurements. To conserve your template material, I recommend that you draw the pattern on paper and then glue or tape the pattern to your template material before cutting it out.

The table below has stitching pattern measurements for each ⅛″ diameter increment from 1 ¾″ to 3″. The values in the **Adjusted** columns account for my 1.064 adjustment factor. The adjusted values decrease the **Base** pattern size so that you will get a more accurate finished size when using corduroy or something similar (a soft, flexible, moderately thick fabric). If you are using a firm denim or a thin, but non-stretch fabric, use the Base value instead. I attempt to explain why in the "Adjusting for the influence of fabric attributes on beanbag size" topic a little earlier in this chapter. The **Inner Pent Side Length** column in the table is the side length of the regular pentagon that would be formed within the circular one if you joined the arc intersections with straight lines.

To draw a cutting pattern, draw everything the same but increase the compass radius for the arcs by the desired seam allowance (I use 8mm). Alternatively, you can draw a regular pentagon for the cutting pattern whose side length is **Inner Pent Side Length** + (desired allowance × 1.4531).

Finished Diameter	**Guide Pentagon Side Length** (mm)		**Guide Pentagon Circumradius** (mm)		**Arc Radius** (mm)		**Panel Height** (mm)		**Inner Pent Side Length** (mm)	
	Base	**Adjusted**	Base	**Adjusted**	Base	**Adjusted**	Base	**Adjusted**	Base	**Adjusted**
1¾″ (44.5mm)	67.070	**63.036**	57.053	**53.621**	69.171	**65.011**	26.460	**24.868**	16.860	**15.846**
1⅞″ (47.6mm)	71.861	**67.538**	61.128	**57.451**	74.112	**69.654**	28.350	**26.645**	18.064	**16.977**
2″ (50.8mm)	76.651	**72.041**	65.204	**61.281**	79.053	**74.298**	30.240	**28.421**	19.268	**18.109**
2⅛″ (54.0mm)	81.442	**76.543**	69.279	**65.112**	83.994	**78.942**	32.130	**30.197**	20.473	**19.241**
2¼″ (57.2mm)	86.233	**81.046**	73.354	**68.942**	88.935	**83.585**	34.020	**31.974**	21.677	**20.373**
2⅜″ (60.3mm)	91.023	**85.548**	77.429	**72.772**	93.875	**88.229**	35.910	**33.750**	22.881	**21.505**
2½″ (63.5mm)	95.814	**90.051**	81.504	**76.602**	98.816	**92.872**	37.800	**35.526**	24.085	**22.637**
2⅝″ (66.7mm)	100.605	**94.553**	85.580	**80.432**	103.757	**97.516**	39.690	**37.303**	25.290	**23.768**
2¾″ (69.9mm)	105.396	**99.056**	89.655	**84.262**	108.698	**102.160**	41.580	**39.079**	26.494	**24.900**
2⅞″ (73.0mm)	110.186	**103.559**	93.730	**88.092**	113.639	**106.803**	43.470	**40.855**	27.698	**26.032**
3″ (76.2mm)	114.977	**108.061**	97.805	**91.922**	118.580	**111.447**	45.360	**42.632**	28.902	**27.164**



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

Manual directions for the Circular Pentagon

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

1. Draw a horizontal line the length of **Guide Pentagon Side Length** and mark each end of it. Continue the line on either side of the marks to aid in accurately aligning a protractor to it. Mark another point (labeled *r* in Illustration 1) the distance of **Arc Radius** from the beginning of the line which will be used to extend the compass to the correct radius.

2. Place a protractor on the line, center it on each of the endpoint marks in turn, and mark points at 108° angles to the base line. Draw a line from each endpoint through the respective angle mark, and mark each line at the distance of **Guide Pentagon Side Length** from the starting side's endpoints, forming half of the guide pentagon. Continue each line beyond the endpoint to help align the protractor to them.

3. Place the protractor on each new line, centered on the new endpoints, and mark points at 108° as in step 2. Draw the two final sides, completing the pentagon. Make sure the lines meet exactly **Guide Pentagon Side Length** from their origin points. If they do, you drew a perfect pentagon. Any error you make will be compounded several times in the juggling bag, so be as precise as you can.

4. Use the radius mark you made on the first line to extend a compass to **Arc Radius**, and then, with the compass placed at that corner of the pentagon, draw an arc within the pentagon.

5. Now place the compass at each of the other corners of the guide pentagon and draw four more arcs within the pentagon. The intersections of these five arcs form the circular pentagonal panel shape. To verify that you drew it correctly, you can compare the height of the circular pentagon

to **Panel Height**, or compare the side length of the inner pentagon (the one formed by joining the corners of the circular pentagon) to **Inner Pent Side Length**.

6. To draw a cutting pattern, draw everything the same but increase the compass radius by the desired seam allowance (I use 8mm) and then draw the five arcs from the same five points using that new radius. You could also just draw a regular pentagon for the cutting pattern since the bulge is so slight. To calculate its side length, multiply the desired allowance by 1.4531 and add that to the **Inner Pent Side Length** from the table.

SketchUp directions for the Circular Pentagon

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

1. Use the polygon tool (Draw menu > Polygon) set to 5 sides and draw a pentagon with radius = **Guide Pentagon Circumradius**, which will result in a pentagon with sides of length **Guide Pentagon Side Length**. (Or just draw the pentagon edge-by-edge with 108° corners as shown in Illustrations 1 – 3.)
2. Draw circles of radius **Arc Radius** centered at each of the guide pentagon's corners. The intersection of the five circles in the center forms the circular pentagonal panel shape. To verify that you drew it correctly, you can compare the height of the circular pentagon to **Panel Height**, or compare the side length of the inner pentagon (the one formed by joining the corners of the circular pentagon) to **Inner Pent Side Length**.
3. To draw a cutting pattern, draw the same guide pentagon but increase the **Arc Radius** by the desired seam allowance (I use 8mm) and draw the circles from the same points. You could also just draw a regular pentagon for the cutting pattern since the bulge is so slight. To calculate its side length, multiply the desired allowance by 1.4531 and add that to the **Inner Pent Side Length** from the table.

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How to Draw the Regular, Straight-Edged Pentagon

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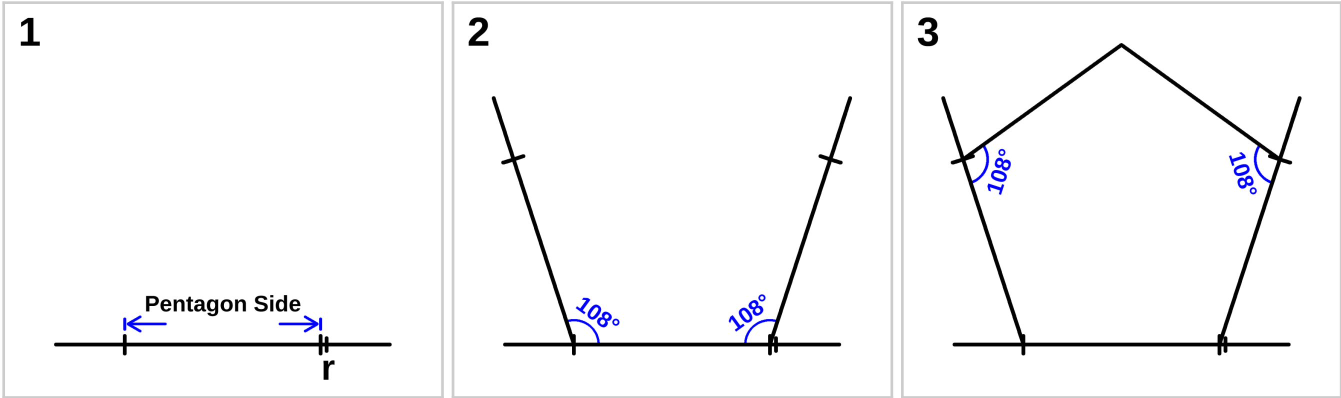
Following the pattern measurements table are manual and SketchUp directions for drawing a regular pentagon. This is simpler and will still result in a good beanbag shape, especially with soft, flexible fabrics. You can also use the regular pentagon to create a cardboard model.

The table below has stitching pattern measurements for each ⅛″ diameter increment from 1¾″ to 3″. The values in the **Adjusted** columns account for the 1.055 estimated adjustment factor. The adjusted values decrease the **Base** pattern size so that you will get a more accurate finished size when using corduroy or something similar (a soft, flexible, moderately thick fabric). If you are using a firm denim or a thin, but non-stretch fabric, use the Base value instead. I attempt to explain why in the "Adjusting for the influence of fabric attributes on beanbag size" topic earlier in this chapter.

To draw a cutting pattern, increase the pentagon side length by the desired allowance × 1.4531, or increase the pentagon circumradius by the allowance × 1.2361.

Finished Diameter	**Regular Pentagon Side Length** (mm)		**Regular Pentagon Circumradius** (mm)		**Pentagon Height** (mm) (for double-checking)	
	Base	**Adjusted**	Base	**Adjusted**	Base	**Adjusted**
1¾″ (44.5mm)	17.123	**16.230**	14.566	**13.806**	26.349	**24.976**
1⅞″ (47.6mm)	18.346	**17.390**	15.606	**14.792**	28.232	**26.760**
2″ (50.8mm)	19.569	**18.549**	16.646	**15.779**	30.114	**28.544**
2⅛″ (54.0mm)	20.792	**19.708**	17.687	**16.765**	31.996	**30.328**
2¼″ (57.2mm)	22.015	**20.867**	18.727	**17.751**	33.878	**32.112**
2⅜″ (60.3mm)	23.238	**22.027**	19.768	**18.737**	35.760	**33.896**
2½″ (63.5mm)	24.461	**23.186**	20.808	**19.723**	37.642	**35.680**
2⅝″ (66.7mm)	25.684	**24.345**	21.848	**20.709**	39.524	**37.464**
2¾″ (69.9mm)	26.907	**25.505**	22.889	**21.696**	41.406	**39.248**
2⅞″ (73.0mm)	28.131	**26.664**	23.929	**22.682**	43.288	**41.032**
3″ (76.2mm)	29.354	**27.823**	24.970	**23.668**	45.171	**42.816**

Directions are on the next page.



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

Manual directions for the Regular Pentagon

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

1. Draw a horizontal line the length of **Regular Pentagon Side Length** and mark each end of it. Continue the line on either side of the marks to aid in accurately aligning a protractor to it.
2. Place a protractor on the line, center it on each of the endpoint marks in turn, and mark points at 108° angles to the base line. Draw a line from each endpoint through the respective angle mark, and mark each line at the distance of **Regular Pentagon Side Length** from the starting side's endpoints, forming half of the pentagon. Continue each line beyond the endpoint to help align the protractor to them.
3. Place the protractor on each new line, centered on the new endpoints, and mark points at 108° as in step 2. Draw the two final sides, completing the pentagon. Make sure the lines meet exactly **Regular Pentagon Side Length** from the previous sides' endpoints. If they do, you drew a perfect pentagon. Any error you make will be compounded several times in the juggling bag, so be as precise as you can. You can also measure the pentagon's height from corner to opposite side and compare it to **Pentagon Height**.
4. To draw a cutting pattern, multiply the desired allowance by 1.4531 and add that to the **Pentagon Side Length**. Or, just draw the cutting pattern around the stitching pattern, using its edges as guides.

SketchUp directions for the Regular Pentagon

(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 5 sides and draw a pentagon with circumradius = **Regular Pentagon Circumradius**, which will result in a pentagon with sides of length **Regular Pentagon Side Length**. (Or just draw the pentagon edge-by-edge with 108° corners as shown in the manual Illustrations.)
2. To draw a cutting pattern, multiply the desired allowance by 1.2361 and add that to the **Pentagon Circumradius**, or by 1.4531 and add that to the **Pentagon Side Length**. Or, just draw the cutting pattern around the stitching pattern, using its edges as guides.

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

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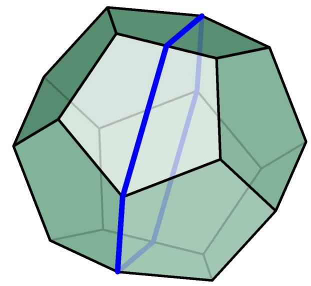
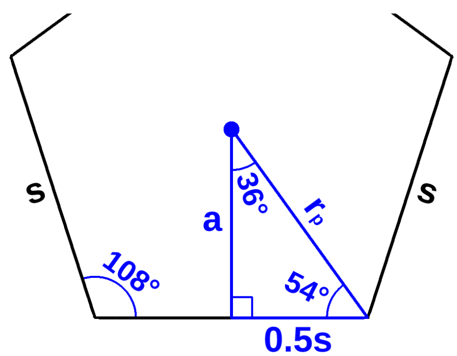
This section describes the math involved in drawing patterns to produce specified beanbag sizes, and creating the pattern sizing formulas. *(The numbers in tiny, right-justified typeface are my computer calculator's unrounded values which I display rounded to six places for brevity.)*

The circumference of the dodecahedron is composed of 4 panel heights and 2 panel edge lengths. To be able to calculate the size of the pentagon, or circular pentagon, needed to produce a desired ball size, I need the relationship between the pentagon's dimensions and the resulting ball circumference. To draw a pentagon manually I need the side length, and to draw it in SketchUp using the polygon tool, which uses a defined circumradius, I need the pentagon's circumradius (center to corner).



In order to calculate those, I first need to express the pentagon's circumradius and height in terms of its side length. Then I can express the ball circumference in terms of the side length and circumradius. Then, once I calculate the circular pentagon's relationship to the straight-edged one, I can express the circumference of the ball in terms of the circular pentagon's dimensions.

Regular dodecahedron panel calculations



Pentagon Circumradius, r_p (center to corner) **=** $\frac{0.5s}{\sin 36°} = \frac{0.5s}{\cos 54°}$ **≈ 0.850651*s*** 0.85065080835203993218154049706301

Pentagon Apothem, *a* (center to edge) = $\frac{0.5s}{\tan 36°}$ = 0.5*s*(tan 54°) ≈ 0.688191*s* 0.68819096023558676910360479095544

The apothem can also be calculated by $\frac{s}{2\sqrt{5-\sqrt{20}}}$

Pentagon Height (sum of above) **≈ 1.538842*s*** 1.5388417685876267012851452880185

I later learned that the pentagon height can also be calculated by the formula

$$\frac{\sqrt{5+2\sqrt{5}}}{2}s$$

But the trigonometric methods are more understandable to me.

Pentagon dimensions expressed in terms of the beanbag circumference and diameter

Now that I have the pentagon's height and circumradius expressed in terms of the side length, I can calculate the relationship between them and the size of the dodecahedral ball they will produce.
(s = pent Side length, r_p = pent Circumradius.)

Dodecahedron Circumference, C, in terms of $s \approx 4(1.538842s) + 2s \approx 8.155367s$ 8.155367074350506805140581152073 8

$$\text{in terms of } r_p \approx \frac{8.155367\,s}{0.850651} \approx 9.587209 r_p$$ 9.5872089866696822130839974872876

Dodecahedral Ball Diameter, D, in terms of $s \approx \dfrac{8.155367\,s}{\pi} \approx 2.595934s$ 2.5959339652235437364184007166685

$$\text{in terms of } r_p \approx \frac{9.587209}{\pi} \approx 3.051703 r_p$$ 3.0517034013670416427359355630513

Pentagon Side Length, $s \approx \dfrac{C}{8.155367} \approx \mathbf{0.122619}C$ 0.12261863762639279737157327218734

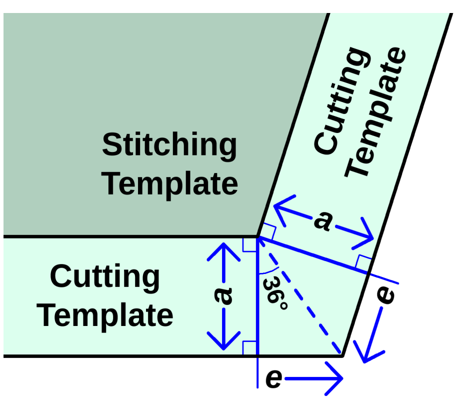
$$\approx \frac{D}{2.595934} \approx \mathbf{0.385218}D$$ 0.38521781116026461449619984654116

Pentagon Circumradius, $r_p \approx \dfrac{C}{9.587209} \approx \mathbf{0.104306}C$ 0.10430564321591689208369729043322

$$\approx \frac{D}{3.051703} \approx \mathbf{0.327686}D$$ 0.32768584245508256393098194129452

Cutting pattern calculations

Designing the cutting pattern requires more trigonometry. In the diagram and first equation below, ***e*** is the amount to extend one end of each side to get a seam allowance ***a***. So **2*e*** is the full amount by which to extend each side for the cutting pattern.



Side Length Extension, $2e = 2(\tan 36°)a \approx \mathbf{1.453085}a$ 1.4530850560107217717909335149612

Circumradius increase $\approx \dfrac{1}{\cos 36°} a \approx \mathbf{1.236068}a$ 1.2360679774997896964091736687312

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The circular design calculations begin on the next page.

Spherical dodecahedron panel calculations

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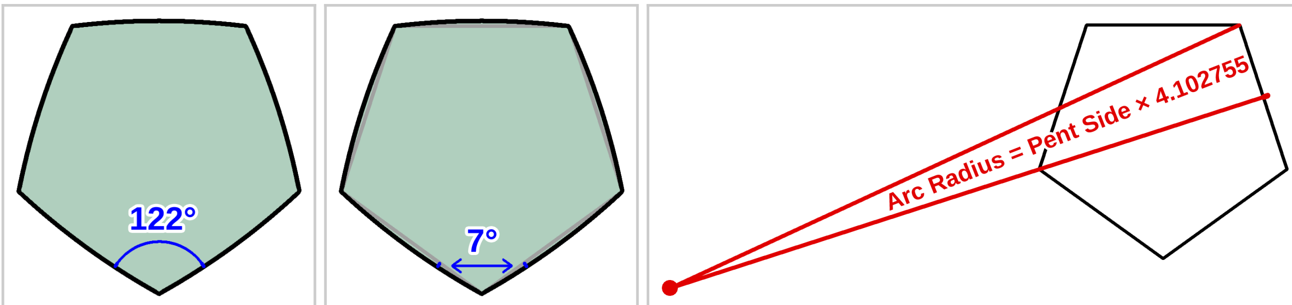
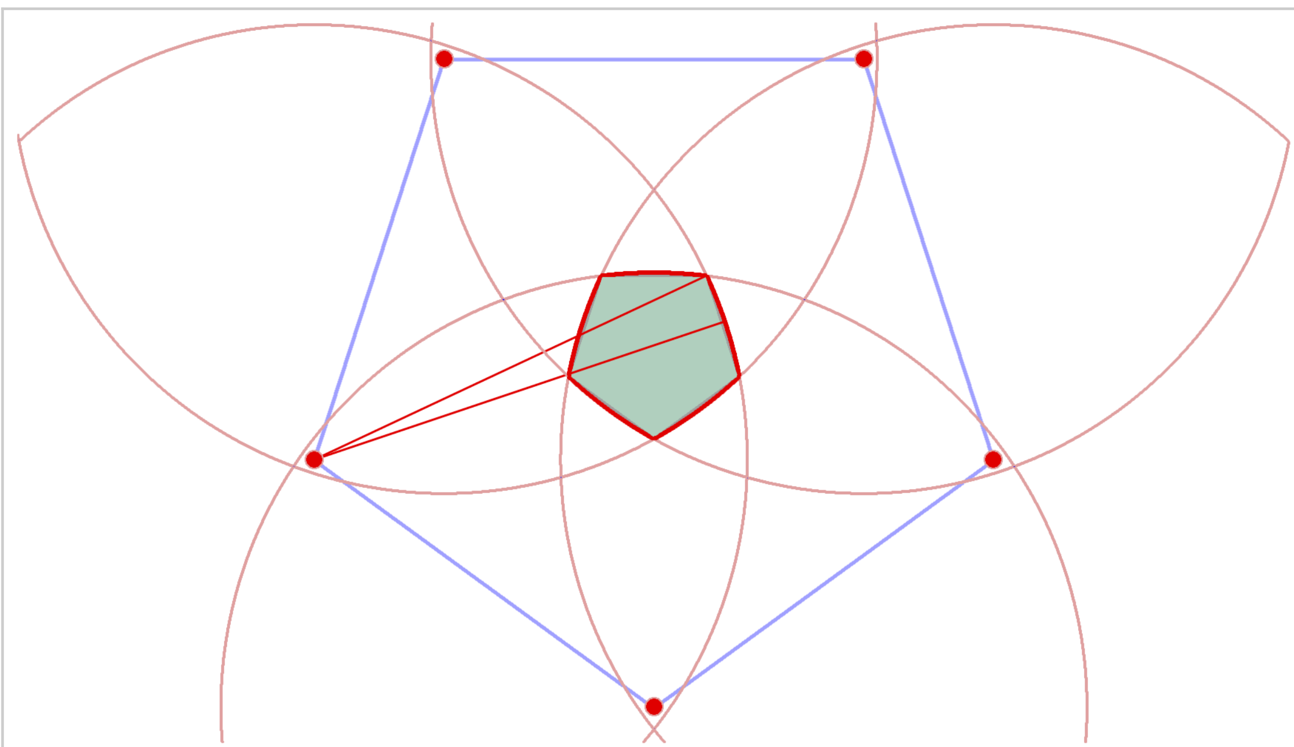
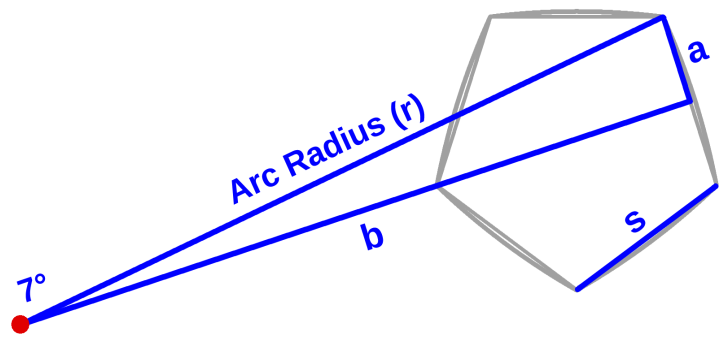
For the circular version of the pentagon I used an arc radius that forms 122° arc intersections. A regular pentagon has 108° corners, so I add 14°, which means the arcs (their tangents, technically) intersect the edges at 7°. Using my edge arc radius formula from Chapter 5, I can calculate the radius needed to produce that arc, which is the first step toward calculating the guide pentagon, whose corners are the circle centers for the arcs that form the circular pentagon:

Arc Radius = $\frac{0.5s}{\sin 7°} \approx \frac{0.5s}{0.121869}$ **≈ 4.102755*s*** (*s* = side length of the inner pentagon) 4.10275452406253916500995933378958





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



$r \approx 4.102755s$ (calculated earlier) 4.1027545240625391650099593378958

$a = 0.5s$

$$b = \frac{a}{\tan 7°} \text{ or } \sqrt{r^2 - a^2} \;\blacktriangleright$$

$$b = \frac{0.5s}{\tan 7°} \text{ or } \sqrt{(4.102755s)^2 - (0.5s)^2}$$

$\approx 4.072173s$ 4.0721732139872970119128306974898

Panel Pentagon Apothem = $0.5s(\tan 54°) \approx 0.688191s$ 0.68819096023558676910360479095546

Guide Pentagon Circumradius, r_g ≈ $4.072173s - 0.688191s \approx$ **$3.383982s$** 3.3839822537517102428092259065344

Guide Pentagon Side Length = $2r_g \sin 36° \approx 2(3.383982s)(0.587785)$ **≈ $3.978110s$** 3.9781097255494016586134693556277

Ratio of Panel Pentagon:Guide Pentagon ≈ 1 : 3.978110

The height of the panel, which I need along with the arc length to calculate the ball's circumference, is the height of the panel pentagon plus the sagitta (height of the apex of the curve above the pentagon's edge). The formula for the sagitta is the following (r = arc radius, s = pentagon side length, or, in this context, the chord). Note that it is simply the arc radius minus side b from above.

$$\text{Sagitta} = r - \frac{0.5s}{\tan 7°} \approx 4.102755s - 4.072173s \approx 0.030581s$$ 0.030581310075242153097128640406

$$\text{Panel Pentagon Height} = \frac{\sqrt{5+2\sqrt{5}}}{2}s \approx 1.538842s$$ 1.5388417685876267012851452880185

Circular Pentagon (Panel) Height ≈ $1.538842s + 0.030581s$ **≈ $1.569423s$** 1.5694230786628688543822739284245

Circular Pentagon Edge (Arc) Length = $2(7°)r\left(\frac{\pi}{180}\right) \approx 14(4.102755s)\left(\frac{\pi}{180}\right)$ **≈ $1.002492s$**

1.0024920478437792379421004816801

To reiterate, the ball's circumference = 4(*panel height*) + 2(*edge length*), so

Spherical Dodecahedron Circumference ≈ $4(1.569423s) + 2(1.002492s)$ **≈ $8.282676s$** 8.2826764103390338934132966770582

Spherical Dodecahedron Diameter ≈ $\frac{8.282676s}{\pi}$ **≈ $2.636458s$** 2.6364577854721857595487594009382

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

So far, I have defined the ball size in terms of the side length of the inner/panel pentagon. Since I know the ratio of the inner pentagon to the guide pentagon, I can re-express the ball size in terms of the guide pentagon, which is what I actually need. Then I will express the arc radius in terms of the guide pentagon. In the formulas, s_g = Guide Pent side length and r_g = Guide Pent circumradius.

Ball Circumference, C, in terms of $s_g \approx \frac{8.282676s}{3.978110} \approx 2.082063s_g$ 2.0820633370526613221303918809352

in terms of $r_g \approx 2(2.082063s_g)(\sin 36°) \approx 2.447612r_g$ 2.447612247716814103628591092303

Ball Diameter, D, in terms of $s_g \approx \dfrac{2.082063\, s_g}{\pi} \approx 0.662741 s_g$ 0.66274134384467602034500815477921

in terms of $r_g \approx \dfrac{2.447612\, r_g}{\pi} \approx 0.779099 r_g$ 0.77909917599279115628114688390526

Guide Pentagon Side Length, $\boldsymbol{s_g \approx \dfrac{C}{2.082063} \approx 0.480293C}$ 0.48029278562466092110977720961397

$\boldsymbol{\approx \dfrac{D}{0.662741} \approx 1.508884D}$ 1.5088842868906122028185015848096

Guide Pentagon Circumradius, $\boldsymbol{r_g \approx \dfrac{C}{2.447612} \approx 0.408561C}$ 0.40856144633727083694664503928673

$\boldsymbol{\approx \dfrac{D}{0.779099} \approx 1.283534D}$ 1.2835336383531905999689814652389

Arc Radius $\boldsymbol{\approx \dfrac{4.102755\, s}{3.978110} \approx 1.031333 s_g}$ 1.0313326698136571096293927846431

$\boldsymbol{\approx \dfrac{1.031333\, s_g}{0.850651} \approx 1.212404 r_g}$ 1.2124042670477806607588407378524

Cutting pattern adjustment

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

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How I Developed This Design

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Figuring out the regular dodecahedron

This was my second beanbag design (the first being the 4-panel orange peel ball). In the 1998 or 1999 Bright, Indiana volunteer fire department festival I played one of the games and won an *el cheapo*, green, vinyl-coated footbag with the BP (British Petroleum) logo on it (BP had just built a gas station in Bright and was advertising itself). I liked the way it was designed: twelve pentagonal panels sewn together to make an almost perfect sphere. It was much rounder and more attractive than my four-panel design, so I decided to try to emulate this new design in my juggling bags.

As I discovered later, aside from looking more elegant, this design also has the benefit of allowing me to be much more creative with color arrangements than the four-panel design. Four is divisible only by 1, 2 and 4 and so I can use only those multiples of colors and produce a balanced look, though, during the drafting of the first edition of this guide, I came up with a very attractive 3-color arrangement. Twelve, on the other hand, is divisible by 1, 2, 3, 4, 6, and 12 and this design also offers numerous ways to arrange the colors on the bag (thirteen that I have come up with so far [*and four more while writing the Second Edition*]).

However, before I could make a twelve-panel beanbag, I had to figure out how to draw a perfect reqular pentagon. (Keep in mind that at this time our family either did not have an internet connection or I did not yet know how to make much use of the internet, so I had to figure everything out myself, or else go to the library.) I tried and failed to come up with a simpler shape (triangle, square, etc) around which a pentagon could be formed using the sides and corners of the inner shape as guides (similar to my stick skeleton idea for the four-panel design). I then knew that I would have to draw the pentagon without any guide.

This meant that I would have to draw a side, measure out the angles at its ends with a protractor, and then draw the adjacent sides. (There are ways to draw a pentagon using circles, but I did not know about these, and I still do not understand them well enough to use them. [*While writing the Second Edition I tried one of those methods and the resulting pentagon was less accurate than if I had used a protractor, and it was much more complicated.*])

So I had to figure out what the measure of the angles should be. I first thought that since a square has a total of 360°, a pentagon might as well. I actually had to draw the first angle before I realized that $\frac{1}{5}$ of 360° is an acute angle which a regular pentagon cannot have. I really didn't think that through very well. I then tried 360° + 180° = 540°. This made each angle 108° which was perfect.

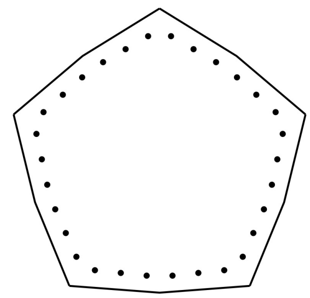
The second problem was what size to make the panels so that the finished bag was the most comfortable size for juggling. This was more difficult than in the case of the four-panel design because both the panel's side length and height are involved in the circumference calculation. Also, I did not know, nor could I come up with, any formula to tell me height (the distance from a side to the opposite corner) of a pentagon. (I did not know much math back then.) I had to figure it out the crude way: by drawing the pentagon (or at least half of it) and then measuring it with a ruler. After arriving at a reasonable circumference I would make a beanbag and, as with the four-panel bags, decide over a period of days or weeks if it fit my hands just right.

I started out making panels with ¾ inch sides. This made the bag a little too small, so I moved up to ⅞ inch. I was almost satisfied with this size, but I decided to try 1 inch. That, at last, seemed perfect and I was pleased that the sides were such a simple length.

I later learned from Dr. Lee Sanders at Miami University's Hamilton, OH campus (where I attended my first two years of college) that the shape of this bag is called a dodecahedron. It has 12 faces, 30 edges and 20 vertices. I learned during the research for the first edition of this guide that the dodecahedron is one of five Platonic solids (see http://en.wikipedia.org/wiki/Platonic_solids for more information).

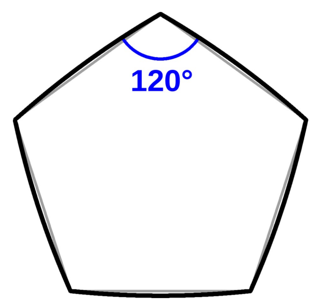
Designing the spherical dodecahedron with curved panel edges

While researching for 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. All but the tetrahedron and baseball use angled bulges, which would create new, and somewhat prominent, vertices on the bag. I didn't like that idea. Billam's bulged pentagon is shown on the right.



Though Billam did not give the definitions for his shapes, it turns out that all the bulges 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.

The reason I guessed that is that in 2013 or so I had read an article on spherical geometry[6] which explained that for polygons to form a sphere, the sum of the angles meeting at each vertex must be 360°. It seems Billam was aware of this, but took the shortcut of using angled bulges. I later learned the mathematics to calculate the radius of the arc that will form a specified angle to a polygon edge. (For a full explanation of this, read the "Curved-Edge Faces" section of Chapter 5). This spherical geometry article and the edge arc radius formula I created enabled me to design the curves for my panels. The dodecahedron, like the tetrahedron and cube, has three corners at each vertex, so the corners must be 120°, which is 12° greater than a true pentagon's angle of 108°.



Marylis Ramos, who published a PDF collection of spherical juggling bag patterns[7], and whose octahedron pattern is the best I know of, has a pattern for a dodecahedron using bulged pentagons, and her bulges are circular. I determined this, and the fact that her curves form 116° angles at the vertices, by comparing her pattern to 120° curves I created in SketchUp, guessing at the correct angle based on how much shallower her curves were, and confirming my guess by comparing a design with 116° curves.

Though my lower panel-count designs – the tetrahedron, cube, and octahedron – require much steeper curves than those that form the mathematically correct angles at the corners due to needing a greater bulge to form circular seams on the bag, I guessed that the dodecahedron would not need steeper curves. Its seams are so short that hardly any bulge would be needed to make the seams conform to the circular profile of the beanbag.

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

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

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

So I made a standard dodecahedron and one with 120° curve intersections using a thin, stiff, tightly woven, non-stretch fabric that I bought for design testing, and compared them. There was a slight, but unmistakable difference between the two. I could easily feel, and even see, that the vertices of the spherical dodecahedron bag were flatter and the bag rounder overall than the regular dodecahedron. The difference is not so great that most people would care, though. I am a perfectionist and I have a great sensitivity to small details.

However, based on those two bags, I decided that the tiny reduction in curvature that Ramos used was not worth trying. In fact, if the 120° curve turned out to be too steep, I decided that adding curved edges was not worth the effort at all. The improvement in the bag shape would be almost imperceptible.

But the 120° curve worked out very well. It was definitely not too steep. I also made a bag with 120° curves out of an elastic denim, just to make sure the curve also worked with the opposite of my test fabric (thick and stretchy). It responded to the panel shape about the same as the test fabric.

I then made a bag with 124° curves just to see if an even steeper curve would work better. Though that bag felt slightly smoother, I could also feel and see a very slight tendency toward inward puckering of the vertices, and a corresponding overly steep bulge of the seams. It was very subtle, but it might be worse with a more loosely woven or stretchier fabric. I think the inward puckering of the vertices was why it felt smoother.

I almost decided to choose the 120° curve, but after experimenting with similar curve intersection angles on the 14-panel design, and further considering the dodecahedron, I decided to go half way and use a 122° curve. The 120° is just a little more angular than I like, and I still think 124° is slightly too much.

To determine which design made the best sphere, I spent a few days occasionally comparing the different bags. I examined them visually at different angles, I rotated them in my hands, feeling the overall shape for any angularity or inward puckering, I ran my fingers along the edges and vertices to feel the contours, and I prodded the vertices to see if they had a tendency to sink inward. It was a very long and nit-picky process.

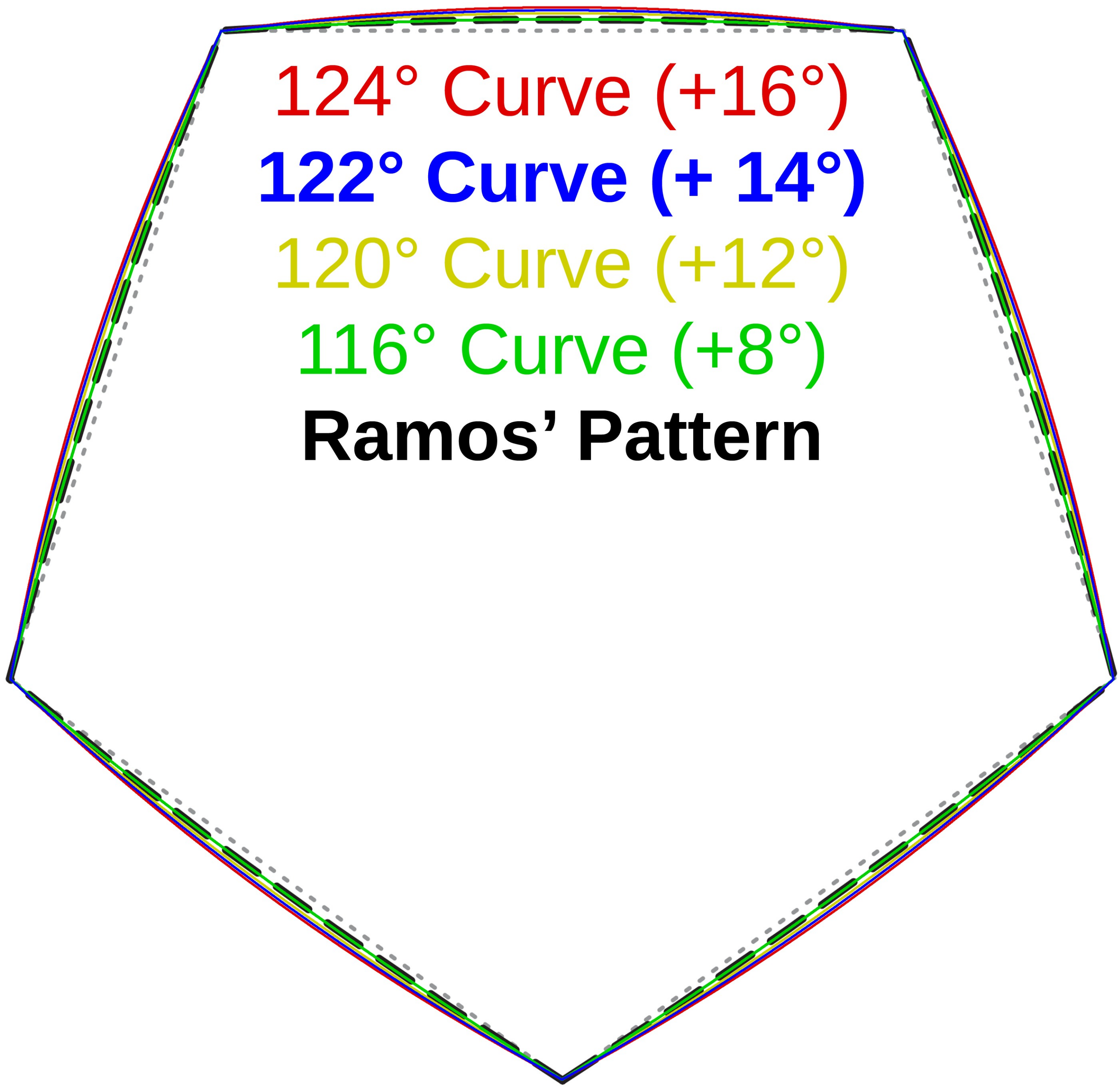
After a couple of weeks, during which I worked on the 14-panel design and began on the 24-panel design, I still felt a nagging doubt about the curve I had chosen for the dodecahedron. I made a 122° bag with the stretchy denim to make sure it worked with that fabric. I compared the two denim bags, both stretched out and loosely filled.

I must be very precise and consistent in how I sew the bags so that such tiny differences can be perceived. I had ironed the seams differently between some of the bags, so to make them more consistent, I ironed them from the outside by pressing the filled bags against the iron so that the filler would press the seam allowances against the iron. This made all the bags so nearly the same that I could hardly tell the difference. Both before and after the ironing, sometimes the 120° bag would feel superior, and sometimes the 122° bag did. In the end, I reaffirmed my choice of the 122° curve.

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. For the 12-panel design I made one with straight edges and one with curved. The two bags were nearly indistinguishable and I was satisfied with the result.

I don’t know why Ramos chose a curve intersection of less than 120°. She made a similar inexplicable choice for her cube pattern in which she chose 115° curves instead of 120°. I contacted her in 2016 but got no reply to my question about her design method.

Below is a comparison of the four curves overlayed on Ramos’ pattern. The green 116° curve is the curve that matches Ramos’ curve.



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