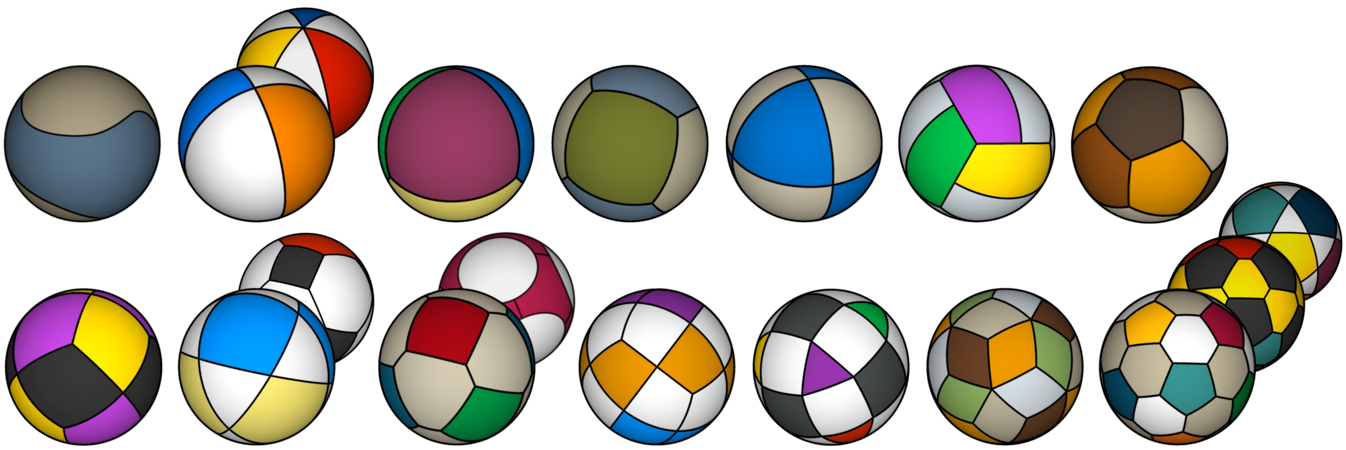
The Complete Homemade Juggling Beanbag Guide

Root Document – Beanbag Instructions Index & Supplementary Chapters

A comprehensive instructional guide and technical treatise on designing and making spherical, paneled beanbags for juggling and footbagging

Third Edition – Now a multi-document guide



By Joshua Clifton
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1st Ed. published late 2012, 2nd Ed. published 11/26/2020, 3rd Ed. published 8/18/2022

Last edited 11/11/2025

This is part of a multi-document guide. Hyperlinks with the icon[1] open **beanbag instructional chapter 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 to this guide. 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**. I am not monetizing the guide, and I am in need of income.

www.joshuaclifton.com/juggle

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INDEX OF BEANBAG INSTRUCTIONAL CHAPTER DOCUMENTS

Each beanbag instructional chapter is a separate PDF document. Store all documents of my guide in the **same folder** so that links to them will work. Clicking a link to a document will open that file (if present). CTRL+Click will open it in a second tab. **If a link to a specific location in a PDF does not open it 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 apps.** In that case you must open document manually and find the linked location. Download any chapters you are missing at www.joshuaclifton.com/juggle.

- **32-Panel Equidistant Truncated Icosahedron (and variations)**
- **32-Panel Color Arrangements**

CHAPTER 1 – INTRODUCTION

Introductions to the Second and Third Edition

Third edition changes

Though I have been continually submitting edits and improvements to the Second Edition guide since publishing it in November, 2020, **the change that prompted calling this the Third Edition was the conversion to a multi-document guide.** This document is the root document. It contains all supplementary chapters and appendices, and an index to the beanbag instructional documents. **Each beanbag chapter is now in its own separate PDF document.**

The third edition also includes the new 30-panel Isovertex Rhombic Triacontahedron beanbag chapter, and an isovertex modification to the 24-panel design. ("Isovertex" is a term I coined to describe a polyhedron with two or more different types of vertices, whose faces have been modified to produce equal sums of corner angles at all vertex types. This produces a better cloth sphere, though not a true polyhedron, because the faces no longer fit together without bending. See Chapter 5 for a full discussion of this.)

I also moved the 32-panel chapter's color arrangement diagrams and Mathematics section into a new section placed after the ready-to-print diagrams, and merged the pattern drawing instructions into that same section. The color arrangements section was so long that I felt it needed to be more out of the way of the rest of the instructions. The change also places those three topics in the sequence with those of the three design variations.

In addition, but less importantly, **I added a cord line orientation guide to the 12-panel dodecahedron chapter** to aid in balancing the orientation of corduroy cords or grainline on the finished ball. I also replaced the 24-panel and 32-panel beanbag photos with photos of newer beanbags I've made, captured a new photo of the 14-Panel, re-edited all the other photos, edited some of the text throughout the documents (often to make it more concise since I tend to be overly verbose), and recreated all the color arrangement diagrams of all chapters in higher resolution and with better perspective symmetry, and changed some of their colors. During this last task I discovered and corrected a few errors I had made in the diagrams, and this prompted me to check all the diagrams for correctness against actual beanbags with colored thumbtacks forming the arrangements. This task also prompted the addition of **three new arrangements for the 32-Panel chapter's Equidistant section**.

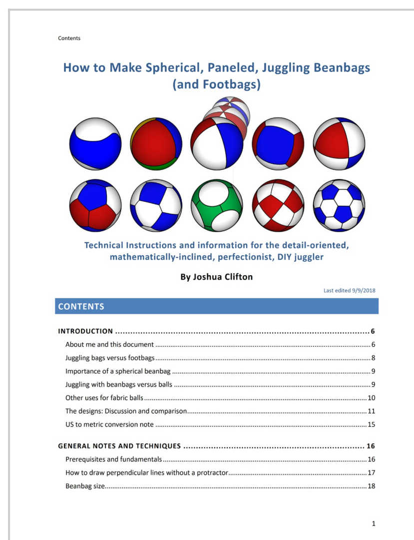
I began working on the multi-document conversion on June 24, 2022 while working on the new 30-panel design chapter. That chapter would add over 30 pages to a document that was already 485 pages long, and I was considering figuring out the 12-panel Volley Bag design and adding a chapter for that soon. **My guide was becoming much too long and cumbersome to browse and edit.**

Adding new design chapters and even making edits that increased the page count required tedious maintenance to the chapter indexes and links to chapters and sections. That will all be much easier now. I hope that this change will also make my guide easier to use.

The switch to multiple documents also eliminates the need for the Condensed Edition. The reason I provided that was that the guide was so huge. People who were overwhelmed by a nearly 500-page document and had no need of all the supplementary information could use the condensed version. Now that they can download only the parts of the guide they want, there is no need for that version. As with many of my other revisions, I am surprised I did not think of doing this sooner.

I did run into one major problem that required a lot of research and experimentation to solve. Links to headings in an external document did not work right. They opened that document, but did not scroll it to the target section, but only opened it at the top, or at the last viewed page. The solution was to create bookmarks in my documents for every chapter or section referred to by any other document, and then link to those bookmarks instead of to the headings. That took a few hours. I also had to tick some specific settings in the PDF export dialog.

Second Edition Introduction: Project details and changes since the first edition


Contents

How to Make Spherical, Paneled, Juggling Beanbags (and Footbags)

Technical Instructions and information for the detail-oriented, mathematically-inclined, perfectionist, DIY juggler

By Joshua Clifton

Last edited 9/9/2018

CONTENTS

1

The first edition of my document was titled *How to Make Spherical, Paneled, Juggling Beanbags (and Footbags)*. I originally published it in late 2012, though I expanded and improved it for several years after that. Since I published it only on my personal website, I doubt many people found it. I did get a couple comments on the included homemade forum, a few emails, and I found a couple references to it on Reddit, so some people found it. I intend to publish this edition on Reddit under the r/Juggling subreddit (I did not know about Reddit last time, and I was not sufficiently familiar with the concept of online communities). I will still host the files on my own website, though.

For this 2020 edition, **I redesigned the panel curvatures for the 4-panel Orange Peel Ball, Tetrahedron, Cube, and Octahedron, and I added curves to the 12-panel Dodecahedron and 14-panel Equidistant Cuboctahedron patterns** *[I had not yet created the other 12 and 14-panel designs]*. I redesigned the 4 through 8-panel curvatures in response to a Reddit contributor who remarked that my octahedron triangles were too steeply curved[3]. I figured out mathematically and empirically that this was true, though I hadn't noticed it before (I was making my beanbags with denim at the time, which I think made the problem less apparent than did other fabrics). Since the Tetrahedron, Cube, and Octahedron all

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

used circular arcs derived from the Orange Peel Ball concept, which produces too steep of a curvature, I needed to rethink them all.

I had learned new mathematical principles since the first edition, and these provided logical starting points and a systematic approach to designing new experimental arcs. **But rather than relying exclusively on math and theory** as I had before, **I took an empirical approach and made many experimental beanbags** with a variety of curves and fabric types, and I was carefully attentive to exactly how the panel curvature affected both the curvature of the finished bags' seams and the nature of the bags' vertices.

For the first phase of the project, which was experimenting with and correcting the Baseball, Orange Peel Ball, Tetrahedron, Cube, and Octahedron (the first five balls of top row in the photo montage at the beginning of this chapter), I made a total of 39 beanbags[4] with seven different fabrics over the course of about a month. I made only one Baseball and I did not make any changes to its curvature, which works well enough as it is, but I may see if I can improve it in the future with Bézier curves instead of circular curves. I did not redesign the Orange Peel Ball at that time, either, but I provided instructions and illustrations for improving its panel shape by hand-drawing a correction to the circular arc to produce, in theory, a better bag shape.

(A few months after publishing the second edition I finally set about experimenting with **corrected curves for the orange peel ball**. That is the one design that **needs a non-circular curve for an optimal beanbag shape**, so it is more difficult to design and draw. I made 22 experimental beanbags and tried six different Bézier-style curves along with the circular curve for comparison using three different fabrics and different grain orientations to arrive at my final panel design. **I also designed the 6-panel pattern**, experimenting with three curves and 7 beanbags. See the Second Edition Update topic in the Orange Peel Ball chapter's "How I Developed This Design" section.)

For the second phase of the project I experimented with curves for the 12, 14, and 24-panel designs, which did not have curves in my first edition. The 12 and 14-panel designs are improved by curved panels, but after trying many curves for the 24-panel design, I concluded that they actually result in an inferior bag shape (at least with some fabrics). The higher panel-count designs do not need curves at all. During this phase I made a total of 28 beanbags[5] with three different fabrics over the course of a little over three and a half months.

(During early and mid-2021 I made 10 additional beanbags as part of further experimentation on the baseball design, and to see how my 4–12-panel designs responded to felt[6].)

The grand total of 106 beanbags as of July, 2021 is more than I have made over the course of my life prior to this project (I recollect 76, which includes an estimated 14 experimental 4-panel orange peel bags while I was trying to figure out that design).

I explain in Chapter 5's "Curved-Edge Faces" section the math and techniques for designing curves for the polygonal faces of polyhedra to make them more spherical. Each instructional chapter also has a **section that explains and illustrates the math** involved in sizing the patterns to produce specified beanbag sizes. The section following that in each chapter, **"How I Developed This Design",**

4 Baseball × 1, Orange Peel Ball × 5, Tetrahedron × 6, Cube × 14, Octahedron × 13

5 Tetrahedron × 1, Dodecahedron × 7, 14-Panel × 6, 24-Panel × 10, 32-Panel Equidistant × 2, 32-Panel Icosidodecahedron × 2

6 4 felt and 1 corduroy baseball (to test new curves and to test how the design responded to corduroy), and 1 felt Tetrahedron, Cube, and Octahedron, and 2 Dodecahedra to see if my designs worked with a non-woven and somewhat stretchy fabric.

gives a detailed account of my process of arriving at the panel shapes. It describes the polyhedra involved, the different panel designs I tried, and why I chose the one I did. It also, in most cases, compares my designs to alternate designs, including Marylis Ramos' patterns[7].

Unlike when I wrote the first edition, I was in a mood in which I was able to enjoy sewing the beanbags (at least for the first two and a half months). Part of the reason I did not do much design experimentation for the first edition was that I found the process of making beanbags very tedious and unpleasant. The other part was that I thought the designs ought to be derived through math and theory; I did not like the random nature of arbitrary panel curve experimentation. Thanks to "peter-bone" in the Reddit thread[8], I changed my mind about that. But it took about five years to feel motivated to redesign my panel curves.

I sought panel curves that made the bags as nearly spherical as possible, producing seams that were neither too straight nor overly bulged, and vertices that were neither prominent nor puckered inward. Yet **I kept the curves circular so that they can be defined mathematically and easily drawn** in any size (except in the orange peel ball). In the case of the Orange Peel Ball and the Octahedron, I discuss how to adjust the initial circular curve to form a non-circular, but more effective curve, and why I do not believe this is important for the Octahedron. *[In October, 2022, I finally designed a Bézier curve for my octahedron pattern. My assumption was correct that the resulting improvement to the ball shape is practically insignificant. See Chapter 5's Curve Shape discussion in the "Curved-Edge Faces" section.]*

I also improved the organization of the document, the pattern sizing and drawing instructions, the tables of pre-calculated pattern dimensions, and especially the ready-to-print patterns, which became the new emphasis of the document rather than an afterthought. I expanded and improved most of the rest of the guide's content, as well, and added new illustrations. **I added many new color arrangement diagrams** (especially to the 32-panel chapter, which lacked this section in the first edition), improved the colors of all my color arrangement diagrams, and **fully fleshed out and illustrated the 32-panel chapter**, which was very minimal in the first edition (it grew from the original 23 pages to 91 at publish time).

On a technical note, the second edition also gave me the opportunity to convert the document from Microsoft Word 2007 .docx format to LibreOffice .odt format. I have been moving away from all Microsoft products except their operating system, but LibreOffice made a mess of my original document when it tried to render it, so I completely recomposed it. I also **edited or recreated most of my illustrations** to take advantage of my **improved techniques**, and to make them **more effective and consistent** with each other. I also **increased their resolution** for greater clarity when printed or zoomed.

I am very proud of my new illustrations. I not only replaced all the unprofessional-looking primary and secondary colors of my old color arrangement diagrams (and some other illustrations like the title balls) with designer colors that I carefully chose from color palettes I found on the web, but my improved Photoshop and SketchUp techniques allowed me to make many of my illustrations more elegant.

I am particularly pleased with the illustrations in the 32-Panel chapter (which were the latest as of when I published this edition), and the especially the illustrations I created for my "Cube Hexes arrangement explanation". I also created illustrations for over six dozen 32-panel color arrangements, and I created

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

8 *"The problem is though that I think his pattern designs rely too much on mathematics for their derivation. Normally I'm a fan of mathematics, but not for beanbag pattern designs. The problem is that the fabric stretches in complex ways. The best patterns I've found have been derived through trial and error. Often the edges of the panels are not perfect arcs."* ~ peter-bone from the Reddit thread illustrated pattern-drawing and beanbag assembly instructions for that chapter, which I had not done for my first edition.

The Second Edition grew to over twice the length of the first edition, which was 176 pages, 56,935 words, and 16.7MB (the Second Edition is 385 pages, 110,055 words, 100.8MB at publish time). I was repeatedly surprised by how immense this document was becoming as I progressed.

My experience with the Second Edition project

Though parts of this project were tedious or stressful, I have enjoyed it. It gave me a reason to get up in the morning and a feeling of purpose and accomplishment, and the satisfaction of a job well done. I am glad to have had this as a hobby, as my twelve years of debilitating, untreatable depression, on top of being an emotionally scarred introvert with an INFJ personality type and mild Asperger's syndrome, has left me unemployable, socially incapable, and with little else to do in life, and little energy or interest with which to pursue anything (I had a lucrative software development career and a healthy social life for a few years before my lurking depression finally overwhelmed me and took them away, leaving me dependent upon family). I have been unable to enjoy video games or most table games, and even reading is sometimes beyond me. Sitting in my rocking chair sewing or at my computer drawing illustrations and writing for hours while listening to audio books or music has been a good way to be occupied and relaxed, and has been an effective palliative.

I began this project in late May, 2020 and spent six months on it before publishing it. For the first couple months I did little else each day but design panel shapes, sew beanbags, draw illustrations, and write this document. I experienced the beginnings of burnout a little over two months in (early August), after drafting the 14-panel chapter, which was very intensive and difficult in terms of mathematics and illustrations. I was also working on the 24-panel design at that time and those take me a long time to make.

I slowed down after that and took more breaks from the project. Slogging through the calculations was particularly difficult during times of increased depression. My mind refused to engage and I could not process the information, and I made many mistakes even when I could. I sometimes had to give up for a while, or work very slowly.

Making the final few 24-panel bags, and especially the corduroy 32-panel bag, went very slowly. My enthusiasm for sewing beanbags was mostly depleted and I spent many days gradually finishing each one. I finally found the motivation to finish the corduroy 32-panel bag the day I wrote this paragraph, October 5th, after over a week of occasionally working on it.

Part of the reason these take so long is that when I make preliminary beanbags for design testing, or the final versions for the photos, I make them as perfectly as possible. I use small stitches and place each one as precisely as I can. For design testing this is important so I get a consistent result between different experiments, enabling me to compare them solely based on panel shape differences. For the final, corduroy bags, precision is important both so I can get a definitive measurement of the finished bag for the adjustment factor, which I use for sizing my patterns, and so they look good in the photos. Making bags for normal use would not take so long.

Incidentally, capturing and editing the beanbag photos to make them look attractive was very difficult and time consuming, as well. Not only was I working with inadequate equipment and no studio, but because the different panel colors of my beanbags reflect differing amounts of light, it is difficult or even impossible to capture a single image that properly exposes all panels. Eventually, **I developed a method of creating HDR images using multiple exposures**. Appendix III discusses my experiences and methods of creating my photos.

I am often suddenly confronted by the oddness of this hobby – the bewilderment of not understanding why I should be fascinated and even excited by forming spheres out of flat fabric panels and researching the math and polyhedra involved, and creating this immense document. Often accompanying that is the thought that this is an absurd and worthless pursuit. I feel a little ashamed of it, especially because I am so far alone in this interest (not that this makes my hobby inherently shameful, but feeling so is human nature).

But I push those feelings and thoughts away. I've learned over my years of depression to take what I can get. I so rarely find anything that can break through the deadness of my mind and heart and stimulate me that when I do, I pursue it for that reason alone. I might lose the hobby if those thoughts took hold on me. I lost most of my interest in juggling years ago. Now I am interested only in designing the beanbags. I hoped for years to learn Mill's Mess and the 5-ball cascade, but I never had the coordination and accuracy for them, or the perseverance to gain the skill.

I might find affirmation if I joined and participated in online forums and communities related to this craft, but unfortunately my depression and weariness (combined, I would guess, with the introvertedness and Asperger's tendencies), can easily cause me to become unfocused and overwhelmed, especially when I am in the middle of an intensive project. I need to keep my focus narrow and my attention on very few things at a time. I felt that the flood of differing ideas, opinions, methods, and information I might get by involving the community would cause mental paralysis and prevent me from doing anything. I felt I needed to finish this document first, and then perhaps revise it according to new information I gained. It would probably benefit greatly from participation by the community, so I hope to be able to join them at some point and get their input.

Closing notes

For the origin story of this project, read the "How I Developed This Design" section of the 4 & 6-Panel Orange Peel Ball Chapter.

To see some of the reason I find polyhedra fascinating, see the polyhedron truncation progressions I illustrate near the beginning of the "How I Developed This Design" sections of the 14-panel Equidistant and 32-panel design chapters. I just added those illustrations today (October 6th).

Obsolete Web Links: Many of the web pages I link to in this document have gone offline. In some cases I have updated the URLs to new pages or deleted the links, but in other cases, particularly citations or image sources, I left the old links in place rather than try to find new sources. You can try entering those URLs into the **Internet Archive Wayback Machine** to see if they have been archived: http://web.archive.org/. I have updated many of the links to the latest archived versions of them when available.

Note About Image Sources: I did not obtain permission to use any of the images from outside sources, but I give credit to the creators and provide the source URLs. All photos and illustrations that are not my own have their sources noted in the adjacent descriptions, or in captions or footnotes.

About Me and This Document (Introduction to the First Edition)

[This was the original introduction, which I edited for the Second Edition]

The original purpose of this document was to provide mathematical definitions, not mere patterns, for spherical beanbag designs so hobbyists can create their own patterns for any beanbag size, and understand the derivation of the designs and improve or adjust them if they wish. (In the Second Edition I began shifting the emphasis to the ready-to-print patterns, but I still provide the pattern definitions.) I also provide instructions for drawing the panel shapes both by hand and using the CAD software, SketchUp.

I am not a serious or very skilled juggler, but I have been casually juggling to some extent for as long as I can remember (I am 42 as of 2020). I briefly took lessons when I was very young (I forget when that was). I can juggle up to four balls and I can juggle several two and three-ball variations. I have not learned to juggle any other objects proficiently.

I also have no great expertise in sewing, but I learned the basics when I was young and I have a natural propensity for craft and DIY projects (I even independently invented the Backstitch). The stitching and assembly techniques I describe are mostly my own, but I have improved them through research.

I have never made beanbags for sale or used my own enough to wear them out, so I have no empirical knowledge of the longevity of fabrics and fillers. My interest lies more in designing the beanbags than in making them. I find the tracing, cutting, and sewing very tedious, though the anticipation of the product I made myself lends some pleasure to the process.

So, I have only very limited experience and knowledge and do not claim to be an authority on the subject of designing and constructing ideal juggling equipment. I have researched most aspects of this craft, however, and compiled many ideas from other people into this guide.

Additionally, I am a perfectionist and tend to be obsessive about detail and precision, and I have a fairly good foundation in mathematics and an aptitude for it. **My aim in designing my panel shapes is not to find a "good enough" design, but to find the optimal design**. I have done extensive research and, for the Second Edition, trial-and-error in the hope of arriving at the best possible designs. I define and explain my designs thoroughly in each instructional chapter, and in most cases even compare them to alternate designs, allowing my readers to check my work and judge for themselves if I have succeeded in my goal.

As for the rest of the guide, I put a great deal of research, calculation, measurement, and testing into making the instructions as comprehensive, accurate, and well-crafted as I can. I explain the motivations and sources behind my designs, methods, and material choices, and I suggest alternatives. If you know more than I do in some areas, my information can serve merely to supplement yours.

Back in the mid-1990s when I was in my mid-teens I began designing and making my own 4-panel orange peel juggling beanbags. My original motivation was saving money, but it soon became a hobby (see the "How I Developed This Design" section of the Orange Peel Ball chapter). Around 1998 I wrote the first drafts of this document, which were only for personal use so I could record what I had learned. At that time I had developed only the 4-panel orange peel ball and straight-edged dodecahedron designs, and the latest draft from that period is eight pages long.

Over the several years of this phase of the hobby I made a total of twenty-six beanbags (not including those I only partially finished or discarded as failed designs). Then I put the hobby aside for a decade or so.

In August, 2012 I became interested in writing a more formal and detailed instructional document to publish on my personal website (which I only give out to people I know). I worked on the formal draft intensively for over a month before publishing it, and I continued revising and expanding it for several years, adding many new chapters and new beanbag designs. It was 51 pages and four designs when I first published it and eventually expanded to 176 pages and nine designs.

My research for the formal guide led me to develop more designs – the spherical cube and octahedron in that first month and others as much as a year and a half later. I continued adding more in subsequent editions of the guide. I became fascinated by the math and concepts involved in designing fabric spheres.

For a chronological history of my designs, read the "How I Developed This Design" section of the instructional chapters in this order:

1. 4-Panel Orange Peel Ball (mid-1990s; includes my origin story)
2. 12-Panel Dodecahedron (roughly 1999, curved panel edges added 11/2020)
3. 8-Panel Spherical Octahedron (8/2012, redesigned 11/2020)
4. 6-Panel Spherical Cube (8/2012, redesigned 11/2020)
5. 14-Panel Equidistant Cuboctahedron (4/2013, curved panel edges added 11/2020)
6. 4-Panel Spherical Tetrahedron (4/2013, redesigned 11/2020)
7. 32-Panel Equidistant Truncated Icosahedron (7/2013)
8. 24-Panel Deltoidal Icositetrahedron (10/1013, redesigned 7/2022)
9. 2-Panel Baseball (2014)
10. 26-Panel Rhombicuboctahedron (5/2021)
11. 30-Panel Rhombic Triacontahedron (8/2022)
12. 12-Panel Rhombic Dodecahedron (4/2023)
13. 14-Panel Spherical Cuboctahedron & Truncated Octahedron (11/2023)
14. 12-Panel Simplified Volleyball/Cube (9/2024)

I found during my research that **there seems to be no document like this one anywhere on the internet or in book form**. Some people offer stitching patterns for spherical juggling bags and a few give some information on materials and techniques and even step-by-step instructions for assembling them, but none of them (except The Shishi Girl, but her fabric balls are not for juggling[9]) define the pattern shapes so the bags can be resized or the designs improved, and nobody I know of has a generalized and in-depth instructional document.

After publishing the first edition guide **I found several tutorials that are pretty good, and I found a few more during the writing of the Second Edition. I have listed them all in the next section.** But

9 "Basic Geometry II" – http://shishigirl.blogspot.com/2008/12/basic-geometry-ii.html

they still don't define the panel shapes beyond Llama Nerds saying in Step 2 of his tutorial that the octahedron pattern is an equilateral triangle and that to avoid "pokey corners" on the bag, the triangle's corners need to be rounded (which is incorrect and potentially misleading as it is the edges, not the corners, that must be rounded[10]; at least the photos of the template and panels serve as a correction). The closest to this kind of article I knew of during the original writing of the first edition was Peter Billam's article on leather balls which has some useful information and gave me a lot of ideas, but is pretty brief.

It may be that nobody is enthusiastic enough about making juggling beanbags to care about the kind of detail I have included. Frankly, I don't know why I am myself. But this document was fun to write and I gained a lot of education in the process, and it has given me a hobby when I very much needed one, so at least I benefited.

After writing the above paragraph (this was in 2013 or so), I found that there is a lot of enthusiasm for making footbags, and there are blogs, forum threads, and YouTube videos dedicated to the craft. This motivated me to add what little I knew about footbags to this guide to make it useful to a wider audience.

It is still hard to find any definitions of the designs, though. I found two online 32-panel pattern generators[11], but no formulas or geometry. I have seen several people asking in forums how to design the panel shapes for a footbag or how to figure out the pattern size needed to produce the bag size they want, and nobody seems to have good answers for these questions. Even the pattern generators (at least the first one I found) create patterns using input panel edge lengths, not a target ball size, so there is still no way to know what parameters to enter to get a desired ball size. My pattern sizing formulas solve that problem, at least for people with an understanding of math. For the rest, my range of ready-to-print pattern sizes with scaling instructions, and tables of pre-calculated pattern measurements should fulfill their needs.

Tutorials I Have Found for Juggling Beanbags, Footbags, & Other Cloth Balls

(Most recent finds at the top. For those that are no longer available, try copying the URL into the Internet Archive Wayback Machine at http://web.archive.org/ and look for an archived version.)

- **DIY Leather juggling ball kit** by Maria del Carmen Aboal Fernández – **A demonstration of sewing leather balls:** https://www.youtube.com/watch?v=bt3ineJ8sik
- **Soft Toys & Amish Puzzle Ball** by Sew, Jahit – https://www.sewjahit.com/post/soft-toys-amish-puzzle-ball
- **Free Fabric Balls Tutorial by Stitches and Love** – http://stitchesandloveblog.blogspot.com/2011/07/free-fabric-balls-tutorial.html
- **Tutorial: Patchwork Play Ball Made With English Paper Piecing** by Abby Glassenberg from *While She Naps* – https://whileshenaps.com/2014/08/patchwork-ball.html

10 Llama Nerds includes photos of his template and beanbag panels with the stitching patterns drawn on them, which clearly have the correct shape, with sharp corners and rounded edges, so this was just careless writing, not a lack of understanding of the design.

11 http://patterns.mhansen.org (no longer available) and http://commo.xtreemhost.com/ (also no longer available as of 2023)

- **Fabric Soccer Balls** by [unknown] from *Seasonal Chapters* – http://seasonalchapters.blogspot.com/2015/04/fabric-soccer-balls.html
- **32 Panel Footbag Stitching Tutorial** by Ivan Builds – https://www.youtube.com/watch?v=xQjZHPBL9F8
- **How to Stitch a 32 Panel Footbag** by Gary Gargan – https://www.youtube.com/watch?v=elZXAJcJDFw
- **Umbrella Footbags** by John Beckerman – http://umbrellabags.wordpress.com/stitching-tutorial/
- **Basic Geometry II** by the Shishi Girl – http://shishigirl.blogspot.com/2008/12/basic-geometry-ii.html
- **Sew Your Own Footbags** by Daniel Botkin – ~~http://valinet.com/~dbotkin/sew.html~~ (offline as of Mar., 2015, but available via the Internet Archive)
- **Making Round Beanbags** from the Coulee Region Jugglers and Unicyclists – http://www.jugglingpoet.com/crju/beanbag.html
- **Barnsey bags how-to** by Dave Barnes – ~~http://www.2diabolo.net/index.html%3Fpage=14.html~~ (offline as of Nov., 2021, but available via the Internet Archive)
- **Custom 'Octohedral' Juggling Bags (or hacky sacks)** by "Llama Nerds" – http://www.instructables.com/id/Custom-Octohedral-Juggling-Bags-or-hacky-sacks/
- **How to make your own juggling balls** from Tunbridge Wells Juggling Club – ~~http://www.twjc.co.uk/howtomakejugglingballs.html~~ (offline as of Apr., 2023, but available via the Internet Archive). This tutorial includes links to **Marylis Ramos' "Sewing Patterns for Jugglers"**, which can also be downloaded from her own web page (archived), or directly at https://jugglingedge.com/pdf/jugglingballtemplates1.pdf (Orange Segment Series) and https://jugglingedge.com/pdf/jugglingballtemplates2.pdf (Polyhedra Series). If they are not available, try downloading them from my own server: Orange Segment Series, Polyhedra Series.
- ***Patchwork Puzzle Balls*** by Jinny Beyer (this is a physical book, not a web resource. I have not read it, but I include many photos both from the book and from projects inspired by it in Appendix I)
- **Juggling Balls: a step by step sewing pattern** by Princess of Chaos and Amiel Martin (Otedama/Ojami-style cubic beanbags) – http://juggleballs.amielmartin.com/
- **How to Make Leather Juggling Balls** by Peter Billam – ~~http://www.pjb.com.au/jug/leatherballs.html~~ [no longer available, except on the Internet Archive[12]: http://web.archive.org/web/20231105094249/https://pjb.com.au/jug/leatherballs.html]

Why Make Beanbags Yourself Instead of Buying Them?

There are many great beanbag makers and a wide variety of designs and options already available. Some manufacturers even allow customers to broadly customize the beanbag characteristics. So why bother

12 Fortunately, I also had already saved my own copy of this web page, as well as Billam's patterns, in anticipation of it going offline someday.

making them yourself? This question was asked in my thread on JugglingEdge.com, and it's a good question, so I decided to expand on my answer here.

Since you are reading this document, you probably already know why you want to make them, but even in that case these points may help clarify your reasons and help you articulate them to others. There are three major reasons I can see for making one's own juggling bags:

- **You're poor** and don't feel comfortable spending the money on a good set, but are adept at crafting and have time on your hands. That's why Dave Barnes and I started (my origin story is in the 4 & 6-Panel Orange Peel Ball document's "How I Developed This Design" section).

  Good, name-brand juggling beanbags and footbags can cost as much as $12–16 each (as of 2023). Some low-end designs are as cheap as $7.50, but if you want a lot of them, that plus shipping still gets a bit expensive when you're short on money. Alternatively, if you've got some old jeans or other good fabric lying around, needle and thread, and some millet, lentils or other filler (or sand or BBs for footbags), **you make make quite a nice set for free**. You might even want to make extras and sell them to fellow jugglers/footbaggers for some extra cash.

- **You want to customize them** in some way that the manufacturers aren't doing. Maybe you want them to be washable or extra durable for a specific use; maybe you want specific colors, fabric type, decorations, character facial features, or glow-in-the-dark or UV-reactive panels; maybe you want a specific firmness or an extra heavy or extra light set; maybe you want to add chimes or bells inside them for a fun auditory effect like Chinese Baoding balls.

- **You love to make things yourself**, and you enjoy the process, creativity, or zen of it, and the satisfaction, pride, and bragging rights of having made something beautiful and excellent (this especially applies to the high panel count beanbags!).

Juggling Bags Versus Footbags

This guide is focused on making juggling beanbags as I am not much into footbagging, but all of the panel structures, with the possible exception of the 4 and 6-panel designs, **can be used for footbags** (a.k.a., Hacky Sacks[13]). Since the primary goal of my designs is to make the bags as spherical as possible, they are in that respect optimized for accurate kicking.

The sizing formulas, tables of pattern measurements, and ready-to-print patterns I provide in each instructional chapter also apply to footbags, though if you gather the seams as is the usual practice, you will have to figure out how much to increase the pattern size so as to get your desired finished size. For a method of doing this, and for information on sizing and measuring your beanbags, refer to Chapter 2, "General Information and Techniques", under "Adjusting/Scaling a Pattern to Produce an Accurate Ball Size".

I have done only a modest amount of research on the craft of making paneled footbags, but from what I have learned, the **differences between footbags and juggling bags are** that **footbags are smaller** (typically 1.8 – 2.25" in diameter according to my research), are **under-filled** for easier stalling (catching and holding on part of the body) and probably to make them more forgiving of bad kicks and

13 "Hacky-sack" is the name trademarked by the toy company Wham-O for the original westernized footbags invented in 1972.

uneven shoe surfaces, often **have more panels** to make them rounder and give them a denser, more supportive seam structure (32 panels appears to be the most common, at least for homemade footbags, and is the freestyling standard according to Wikipedia), and often (maybe always) **have gathered seams** which I assume makes them more springy.

If you want to use my designs to make footbags and want an enthusiast-grade result, I recommend that you research the craft first to learn how to choose your size, shell material, panel count, stitching technique, filler type, amount of fill, weight, and any other important attributes. Wikipedia is one good place to start: http://en.wikipedia.org/wiki/Footbag. There are also many tutorials (text and video) and forums on the craft. The list in the previous section includes some good footbag tutorials. **I compiled a few notes on footbag filler and weight in Chapter 2**, "General Information and Techniques", under "Filler and Beanbag Weight", subheading "Filler and weight for footbags". **I also compiled fabric advice in the same chapter** under the "Fabric" heading (Ultrasuede LT/Light, sometimes referred to as "facile", is the most popular material, and can be purchased from Fields Fabrics, among other stores).

Some footbag manufacturers have articles on their websites discussing the various properties of footbags and give advice on choosing your style. You can use my list of juggling beanbag and footbag manufacturers in Appendix IV to browse the websites I used for some of my research.

If all you want is a small beanbag to kick, my techniques and materials will probably work perfectly well. Just fill the bag to 35 – 75% full (according to my research) to make it stallable and more forgiving, use a fairly heavy filler (sand and BBs are commonly used), and I recommend using one of the higher panel count structures for better roundness. The octahedron (8 panels) and dodecahedron (12 panels) are good, minimal-panel choices if you aren't ambitious enough to go higher. From what I have read, more panels yield a truer and more responsive kick due to being more spherical and rigid, but these qualities also make the bag harder to stall as it rolls more easily. Using a thin, flexible fabric and a heavy filler should help make the bag floppy enough to stall.

Importance of a Spherical Beanbag

Popular, non-spherical juggling beanbag designs.
Image sources: **Left:** http://www.instructables.com/id/Beginner-Juggle-Bags/, **Middle:** http://www.things-to-make-and-do.co.uk/fabric-and-sewing/how-to-make-a-juggling-bean-bag/how-to-make-a-juggling-bean-bag.html, **Right:** my old Jugglebug beanbags.

A spherical shape is important in any ball-type juggling object so that no matter how it lands in your hand you can grip it the same. Small adjustments of grip that a non-spherical shape requires each time you catch it will make juggling more difficult and error-prone. This is **even more important for footbags** because you need to be able to kick them accurately.

All of my patterns produce approximately spherical bags. Those with 6 or fewer panels, however, can feel a little angular across the seams when made with stiff, non-stretch fabrics (due to the large size of the panels that requires them to stretch a lot to conform to a spherical shape). Their seams are circular, though, and their corners are pleasantly rounded, not sharp. The remaining angularity is too mild to be a significant hindrance to juggling, and it can be nearly eliminated by pressing the finished and filled bag against a hot iron along all the seams. This helps reshape the fabric into a spherical shape. Filling the bag loosely also helps because your grip (or kick) reshapes the ball. These techniques would probably allow even my spherical cube to work well for footbagging.

A spherical beanbag requires more skill and knowledge to design and, in most cases, more time and effort to make than the classic, flat, corn hole-style beanbag or even a simple polyhedral beanbag such as a cube or pyramid, but it will be easier to juggle or kick, feel more pleasant in your hand, and look more elegant.

The photos above show examples of popular, non-spherical designs for juggling beanbags. The first design uses one rectangular panel folded in half or two squares, the pyramids are made with two squares, and the cubes use one long rectangle to cover four faces and two squares for the remaining faces (cubes can also be made using two perpendicular rectangular panels that cover three faces each). Very simple designs, but not as good for juggling and almost useless for footbagging.

Juggling with Beanbags Versus Rigid Balls

The **benefits of juggling with beanbags over rigid balls**, aside from the fact that **you can make them yourself and customize them** any way you want, are that they **do not bounce away** when you drop them or collide them in mid-air, they **roll much less** than a ball, they are **easier to catch**, and they can be caught more easily on other parts of the body (**stalled**) similarly to a footbag. They are **recommended for beginners** because of the relative ease of catching them.

Russian balls have the dead fall and anti-roll characteristics of beanbags, but because they are only partially filled with heavy filler which sits in an otherwise empty ball, they are unbalanced and will wobble in the air if you give them any spin.

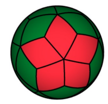
There are various other types of rigid balls with differing characteristics. Wikipedia has information on some of them and their relative benefits (http://en.wikipedia.org/wiki/Juggling_ball). Your juggling practices, skill level, and personality will, of course, determine which types you prefer and I do not claim that beanbags are superior to other types of balls. They just happen to be the type in which I am most interested.

Other Uses for Fabric Balls

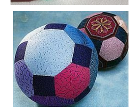
Fabric balls can be used for more than juggling or footbagging. Here are some ideas:

- **Indoor games of catch or general indoor throwing** (consider a lightweight filling, such as a mix of fiber fill and plastic pellets, for less danger to lamps and other household items)
- **Indoor kickballs** (when made soccer ball size and stuffed with soft stuffing)

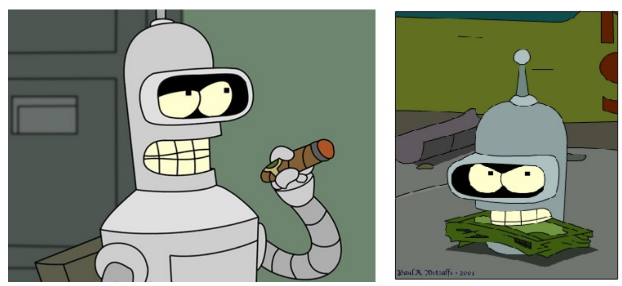
- **Swimming pool splash balls**. Fill any fabric bag with an absorbent, sponge material and you have a watery, splattery, harmless ball for throwing in a pool.
- **Grip strengthening or stress reliever balls**. If you want the ball to squash, use a stretchy fabric and a small, smooth, fluid filler such as millet or flaxseed. I think the baseball and cube designs would make the best stress-reliever balls due to their large and evenly distributed seamless areas that would stretch well when the bag is squeezed.
- **Baby toys** (best when made larger and stuffed with something soft, with perhaps a bell or rattle inside; you might also consider quilting contrasting figures or letters onto each panel or attaching beads, bells, and miniature stuffed figures by ribbons). See Appendix I for examples of this.
- **Unbreakable Christmas ornaments** (made with soft stuffing, colorful trim, and a loop for hanging – see Appendix I for an example of this)



- **Decorative centerpieces** (made with elegant solids or prints, or with leather – see Appendix I for examples of this)



- **Throw-pillows** (made large and filled with fiberfill). The Japanese otedama design may be better suited to this, though, depending on the application. I wrote a section on these in Chapter 4.
- **Beanbag chairs** (by making them very large)
- **Ye olde dunking booth ammunition**. The Maryland Renaissance Festival's "Drench-a-Wench/Soak-a-Bloke" game uses softball-sized, leather, sand-filled, cube beanbags.
- The top of Bender's head, or any other **spherical or hemispherical shape such as a hat**. Years ago I wanted to build a costume of Bender the robot from *Futurama* using mainly gray vinyl and foam rubber. I realized that I could form the domed top of his head out of the vinyl using two orange peel panels laid horizontally or four circular triangular panels to form a hemisphere and then stuff it with fiberfill to round it out. The rest of his head would be a cylinder with the facial features cut into it. I have not yet made the costume, but it'll be great if I do. It will have a working chest cabinet that holds two bottles of beer and a cigar (if my belly is lean enough to make room for them).



Images © 2020 Comedy Partners. Second image from http://slurmed.com/?p=fanart/@fanart&name=paul&pag=9.

The Beanbag Designs: Discussion and Comparison

Discussion of the panel shapes and structures

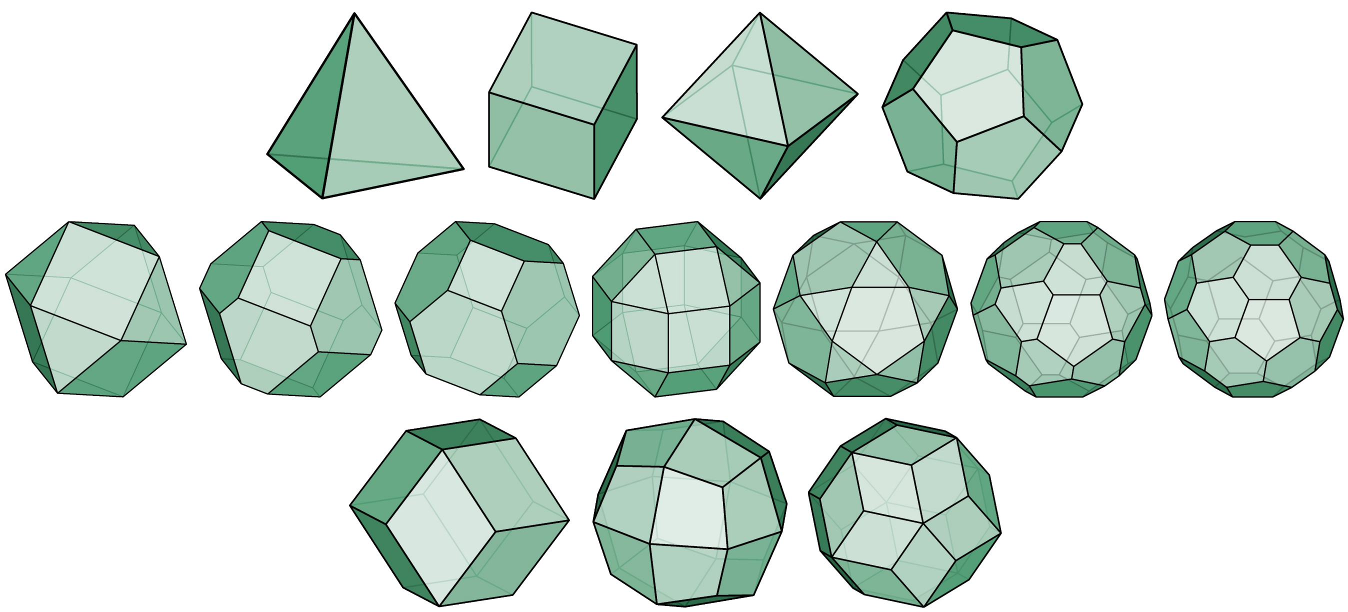
I designed all the panel shapes in these documents myself (except for the regular polygons, of course), but I referenced other designs. The panel *structures* are not my own. I based my structure designs on panel structures used by manufacturers and hobbyists. I picked designs I liked and figured out how to emulate them or turn the polyhedra they were based on into optimal spheres. The notable exception is the Rhombic Dodecahedron, which I designed in April, 2023. I am the first to figure out how to turn that polyhedron into a spherical beanbag as far as I know.

In the "How I Developed This Design" section of each instructional chapter I provide in-depth explanations of the motivations and methods behind my panel shapes, and in the "Mathematics" section I provide a full, illustrated explanation of the math behind the formulas for calculating the pattern dimensions given a desired ball size. With this information you can learn the derivation of my designs and improve them if you know more than I do.

All of the designs up to 14-panels have curved panel edges so as to produce better approximations of spheres. This means that even the tetrahedron and cube, though noticeably angular across the seams (with stiff fabrics), are pleasantly rounded and have no sharp corners. The octahedron is an almost perfect sphere. Most of the higher panel-count designs, while not curved, are modified to produce better spheres than the normal polyhedra would.

The first four of the five Platonic solids are represented in this document. The five **Platonic solids** are the tetrahedron, cube, octahedron, dodecahedron, and icosahedron. The cuboctahedron, truncated octahedron, and truncated icosahedron, which are the bases of my 14 and 32-panel designs, and the 26-face rhombicuboctahedron, are **Archimedean solids**. My rhombic dodecahedron (12 panels), deltoidal icositetrahedron (24 panels), and rhombic triacontahedron (30 panels) are based on **Catalan solids** (duals of Archimedean solids). These polyhedra are all shown below.

For information on Platonic, Archimedean, and Catalan solids, look them up in Wikipedia. **They and the relationships between them are fascinating if you enjoy that sort of thing**. For a taste of this, see the polyhedron truncation progressions I illustrate near the beginning of the "How I Developed This Design" sections of the 14-panel Equidistant and 32-panel chapters.



Polyhedra on which I based my beanbag designs

Top Row – The First Four Platonic Solids: The Tetrahedron, Cube, Octahedron, and Dodecahedron.

Middle Row – Archimedean Solids and Modifications: The 14-face Cuboctahedron, my Equidistant version of it, and the related Truncated Octahedron, the 26-face Rhombicuboctahedron in the middle, and the 32-face Icosidodecahedron followed by my two modified versions of it.

Bottom Row – Catalan Solids: The 12-face Rhombic Dodecahedron, 24-face Deltoidal Icositetrahedron, and 30-face Rhombic Triacontahedron.

Design comparison

Following is a comparison of the designs to help you decide which one to make. In Chapter 2, “General Information and Techniques”, there is section on roundness and uniformity which may also be helpful. Each instructional chapter also begins with a brief discussion of the design and color arrangement ideas.

For low panel-count designs that have a tendency to feel a little angular with stiff fabrics, **pressing the finished and filled bag against a hot iron along all the seams will make it much more spherical**. It rounds and smooths the seams and even reshapes the panel faces into a more spherical shape.

Continued on the next page

The lengths of stitching noted in this table are for 2.5” bags. I made all beanbags pictured.

2-Panel Baseball – 1 seam, 15.1”/38.44cm of stitching

Best for those who like the baseball or yin-yang look. I also think it and the cube would make the best **stress-reliever squash balls** due to their large and evenly distributed seamless areas that would stretch well when the bag is squeezed.

The baseball is **mostly spherical** and feels better in the hand than the 4-panel orange peel ball because of the compound curvature and greater uniformity of the seam, but at the profile shown on the left (and only at that profile) it can be **a bit squarish**, at least before being broken in. **Ironing the finished and filled bag along the seam will reshape it into a better sphere. Using a flexible, stretchy fabric or filling it loosely will also improve it.**

The panel design is significantly more complicated than the other low panel-count designs, and the bag is **much more difficult to make** than the other designs because attaching concave and convex curves to each other requires careful and continual realignment of the panels during sewing. So **I don’t recommend it for beginners**.

Orange Peel Ball (Hosohedron)

- **4-Panel** – 4 seams, 2 vertices, 17.1”/43.53cm of stitching
- **6-Panel** – 6 seams, 2 vertices, 23.8”/60.37cm of stitching

The 4-panel version is good for those who want a **decently spherical beanbag with minimal time, effort, and complication**. It is roughly tied with the tetrahedron for being the least round and elegant of the designs, but also the simplest and quickest to make. It feels **a bit less spherical** in my hand than the baseball because of the strictly longitudinal seams. As with the baseball, you can **iron the finished and filled bag along the seams, use a stretchy fabric, or fill the bag loosely for better sphericity.**

The 6-panel version is good for those who like the stripey look of it, but I don’t see any other merit to it. The **octahedron makes a better and more uniform sphere** and has more versatility in color arrangements, and yet requires about the same amount of work.

4-Panel Spherical Tetrahedron – 6 seams, 4 vertices, 16.0”/40.56cm of stitching

This design is about as **quick and simple to make** as the 4-panel Orange Peel Ball, but it has a more uniform seam and vertex distribution (which may be preferable to some). Its **asymmetric, pyramidal shape** can also be a fun novelty.

This design is as pyramidal as the 4-panel orange peel ball is cubic (only mildly with soft fabrics), so which design you choose will mostly depend on which type of non-spherical shape you prefer. **Ironing the finished and filled bag along the seams, using a stretchy fabric, or filling it loosely will help it feel more spherical**. With a soft corduroy or similar fabric it is surprisingly spherical for such a non-spherical polyhedron. My stiff, non-stretch design testing fabric made it significantly angular, however (until I ironed it).

Note that the 12-panel Rhombic Dodecahedron can produce the look of the tetrahedron with much better roundness.

6-Panel Spherical Cube – 12 seams, 8 vertices, 19.6”/49.73cm of stitching

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. I also think it and the baseball would make the best **stress-reliever squash balls** due to their large and evenly distributed seamless areas that would stretch well when the bag is squeezed.

I like the look and feel of this design. It is **more uniform than the orange peel ball** and feels better in my hand. It will still feel a little angular across the seams when made with a stiff fabric, but **ironing the finished and filled bag along the seams will reshape it into a better sphere.** (**If you want the cubic visual aesthetic but with better roundness, choose the 12-panel Simplified Volleyball/Cube**, or, for even more roundness and a denser seam structure, **you can arrange the 24-panel Deltoidal Icositetrahedron to look like a spherical cube**.)

8-Panel Spherical Octahedron – 12 seams, 6 vertices, 24.0”/61.01cm of stitching

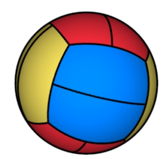
This design has the **best balance between overall excellence and ease of manufacturing**. It has a high degree of roundness and seam uniformity, is quite elegant, and has a wide variety of color arrangement possibilities, and yet it is a simple design with a low number of panels, making it relatively quick and easy to make compared to the 12 and above panel-count designs.

This panel structure **supports all the color arrangements of the 4-panel orange peel ball** as well as several unique arrangements.

If you want the 8-panel visual aesthetic but with perfect roundness and a denser seam structure, **you can arrange the 24-panel Deltoidal Icositetrahedron to look like a spherical octahedron**.

12-Panel Simplified Volleyball/Cube – 18 seams (12 cube edge seams, 6 mid-panel seams), 28.3”/71.80cm of stitching

This design is a spherical cube modified to have a curved seam in the middle of each panel, which **eliminates nearly all cubicness from its shape, making it very spherical**, and giving it a volleyball-like appearance. Like the cube, it has a balanced stretch. It can be made to look like a cube as shown on the right, or can have pinwheel arrangements as in the photo. **It is simpler to make than the other 12-panel designs, and I think its seam structure will be easier to sew with a sewing machine.**



12-Panel Spherical Dodecahedron – 30 seams, 20 vertices, 26.8”/68.08cm of stitching (+10% or 33.3% duplicate stitching using my assembly methods)

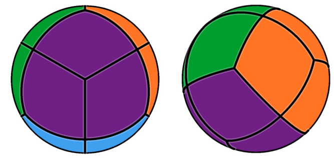
Best for those who value a **high degree of smooth roundness and seam uniformity** and don’t mind the extra work. **This design is as smooth and spherical as any of the higher panel-count designs**, so if that is what you value, you needn’t make anything more complicated than this. Even without curved panel edges the dodecahedron is quite spherical – more so than the straight-edged 14-panel designs.

The shortness of the seams makes them potentially smoother than those of the lower panel-count designs because they don’t have as steep a curvature around the bag and therefore won’t pucker as much (though the others won’t pucker much, either, if you iron them flat or use a thin, flexible fabric). Ironing the seam allowances is more practical than in the higher panel count designs, making this potentially smoother than those.

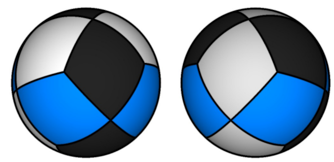
The dodecahedron also supports **many interesting color arrangements.**

12-Panel Spherical Rhombic Dodecahedron – 24 seams, 14 vertices (3-way × 8, 4-way × 6), 28.7”/72.83cm of stitching (+8% or 17% duplicate stitching using my assembly methods)

This design **is simpler to assemble than the regular dodecahedron and 14-panel designs, and supports unique and fun color arrangements**. Depending on the fabric used, it may not be quite as uniformly round due to the elongated shape of the panels and the two different types of vertices, but this is only a perfectionist’s nit-pick. It has a correspondence to the tetrahedron as shown on the right, so **if you like the look of the spherical tetrahedron but want more roundness, you can use this structure**.



Because its structure is composed of three circumscribing, perpendicular rings of four panels, the **stretch direction of woven fabrics will be balanced** simply by orienting the grain along the same diagonal on all panels.



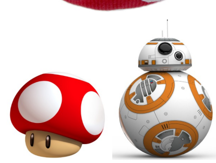
14-Panel Spherical Equidistant Cuboctahedron – 24 long seams, 12 short seams, 24 vertices, 29.9”/76.06cm of stitching (my assembly methods add 7.7% or 42.3% duplicate stitching)

Roughly tied with the regular dodecahedron for roundness and uniformity (when using the curved-edge patterns), but with a very different, and more complex, visual aesthetic. Best for those who value **greater visual complexity and beauty, or enjoy a checkered or soccer ball-like color pattern**. This design (and especially the hex shape) is somewhat **more complicated and difficult to make** than the dodecahedra due to having two different panel shapes, two different edge lengths, and two more panels to cut out and sew.

This panel structure can be modified to produce the two structures shown on the right. The Polka Dot version is the same structure as the Super Mario Bros. mushroom and the BB-8 droid from Star Wars. It is simply the result of **converting the squares into circles**. The instructional chapter document has a section on each of these modifications.

Polka Dot

Poké Ball



[14]

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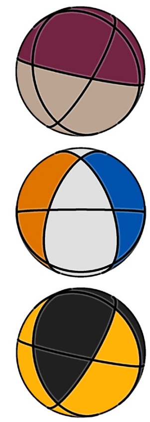
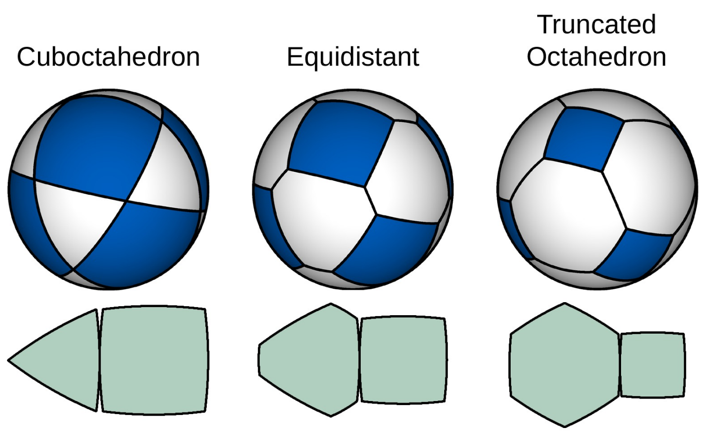
14 Super Mario Bros. Mushroom image from https://mario.fandom.com/wiki/Super_Mario_3D_Land/Gallery. BB-8 image © & ™ LucasFilm Ltd.

14-Panel Spherical Cuboctahedron & Truncated Octahedron – Cuboctahedron: 24 seams, 12 vertices, 31.3”/79.52cm of stitching. Truncated Octahedron: 36 seams, 24 vertices, 28.8”/73.26cm of stitching (my assembly methods add 16.6% or 33.3% duplicate stitching).



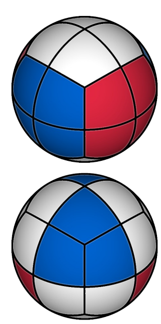
These are the Archimedean variations of my original 14-panel design. I put them together in one chapter. These are a little less uniformly round than the Equidistant design (especially the truncated octahedron), and less attractive in my opinion, but they have a distinctive appearance that some might prefer. The cuboctahedron, because it has triangles instead of hexagons,

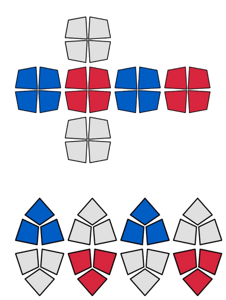
supports the color arrangements shown on the right which the other two don’t. It is also a little less complicated to assemble due to having fewer seams, and only one edge length unlike the Equidistant design.



Comparison of the three different 14-panel designs.

24-Panel Isovertex Deltoidal Icositetrahedron – 24 short seams, 24 long seams, 26 vertices, 42.5”/107.95cm of stitching (my assembly method adds 14.7% duplicate stitching)

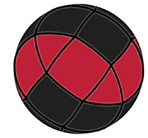




Perhaps the most important benefit of this design is that it is **essentially a spherical cube or octahedron** (or a 4-panel orange peel ball) **but with more panels** as shown on the right. Its seam structure is a combination of those two. So **if you like the look of those designs but want a denser, more uniform seam structure or more roundness, this is the design for you**. It also **supports several unique color arrangements**.

While this design has a relatively large number of panels, it has an advantage over the 14, 26, and 32-panel designs in that it uses **only one panel shape**. My method of assembly also makes it **simple to make**.


26-Panel Rhombicuboctahedron – 48 seams, 24 vertices, 44.3”/112.62cm of stitching




This design **supports beautiful checkered color arrangements as well as many other great arrangements**. The smaller beanbag photo uses an arrangement I invented. The 26-panel structure is **more versatile than the 24-panel structure** (if you don’t count the fact that the 24-panel supports all the arrangements of the Orange Peel Ball, Cube, and Octahedron). I also think **its color arrangements are in general more interesting and attractive** than those of the 24-panel. However, it is more complicated to make**.**


30-Panel Isovertex Rhombic Triacontahedron – 60 seams, 32 vertices (3-way × 20, 5-way × 12), 48.1”/122.05cm of stitching (my assembly method adds 10% duplicate stitching)



With its combination of 3-way and 5-way vertices, this design has an intriguing and mesmerizing seam structure that supports many beautiful and distinctive color arrangements. It also has a correspondence to the cube and octahedron and supports color arrangements related to those designs. **It is simpler and easier to make than the 26 or 32-panel structures because it has only one panel shape and one edge length, and because my assembly method is simpler and more straight-forward than for those structures.**

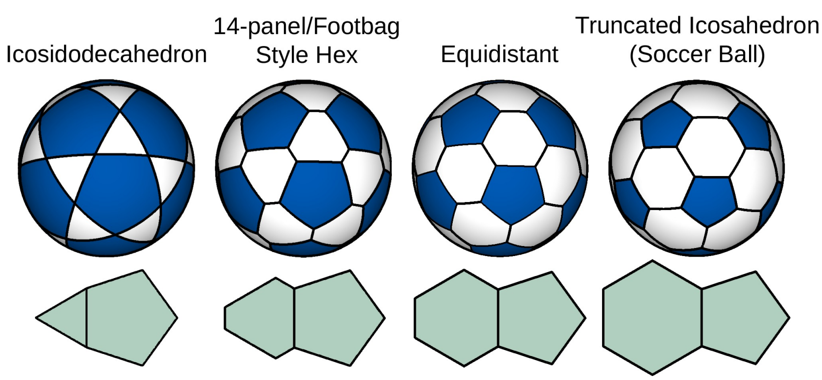


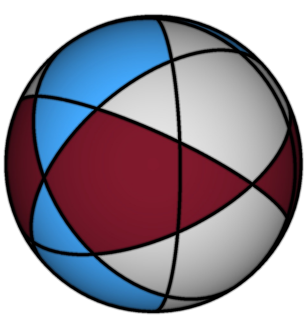
32-Panel Equidistant Truncated Icosahedron – 60 long seams, 30 short seams, 60 vertices, 45.3”/115.05cm of stitching (my assembly method adds 16.7% duplicate stitching)

The main benefit of this design is that it **supports a huge number of dazzling color arrangements**. I have created diagrams for about **six dozen arrangements**. Additionally, this design or its variations **can be made to resemble various objects, creatures, and characters** (see the instructional chapter for examples). Also, the dense network of 90 seams makes a pleasing tactile texture on my denim bag.

The huge number of seams and the two different edge lengths make this design **a relatively complicated, difficult, and time-consuming project**. I recommend using a fairly **thin fabric that does not fray** such as Ultrasuede, though **corduroy worked very well**. Denim was a bit of a frizzy mess to sew.

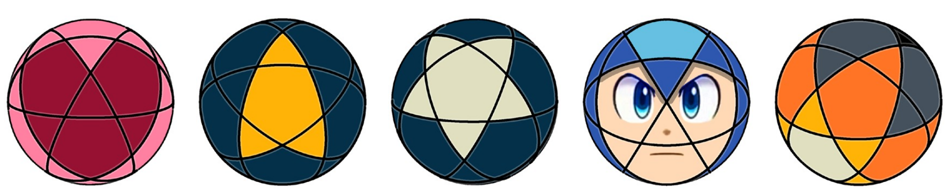
I include **three additional variations of this design**. One has more triangular and proportionately smaller hexes (like those typically used for footbags), allowing for **better creature and character likenesses** (I created the turtle arrangement on the left with that variation). The other two are Archimedean solids: the icosidodecahedron with triangles instead of hexagons (the next design below), and the truncated icosahedron/soccer ball with regular (equilateral) hexagons.





32-Panel Icosidodecahedron – 60 seams, 30 vertices, 47.2”/119.99cm of stitching (my assembly method adds 16.7% duplicate stitching)

This is a variation of the above design and is in the same chapter, though in its own section like the other variations. **The triangles in place of the hexagons allow for some unique color arrangements**. Below are some I invented myself. I am very proud of the fifth, “Sozen’s Comet”.



CHAPTER 2 – GENERAL INFORMATION AND TECHNIQUES

Chapter Index

Prerequisites and Fundamentals

Sewing skills

This guide assumes you have at least some basic experience with sewing, and hand-sewing in particular (I neither use a sewing machine nor describe any techniques for one, but Dave Barnes has a tutorial on making orange peel “Barnesy Bags” with a sewing machine. That tutorial is now available only via the Internet Archive Wayback Machine). I describe stitching techniques and use terminology in a way that someone with no experience at all may not be able to follow. I provide instructions for the **backstitch** (the stitch I use) and describe many tips and techniques for using it to make beanbags, but they are not well illustrated, and are probably not as complete as a beginner would need. If you have never sewn anything before, I recommend that you find a sewing tutorial and **sew some simpler projects first**, or perhaps my 4-panel Orange Peel Ball or Tetrahedron design, which are very simple.

If you have not made something like this before, I also recommend that you **consider your first bag or two practice bags** and use inexpensive materials like felt. If you are particular about the size of your beanbags, you should also assume that the first bag made with your intended materials is a **sizing experiment**. It may not be the size you expected, especially if you gather the seams, and you will need to measure it to get your **pattern adjustment factor** so the rest are the correct size (see the section titled “Adjusting/Scaling a Pattern to Produce an Accurate Ball Size”).

I have never gathered my seams, so this is a technique I cannot provide advice for in my guide. Footbags usually have gathered seams, so if you are making footbags, I recommend finding tutorials dedicated to that craft. I provide a list in the previous chapter of Tutorials I Have Found for Juggling Beanbags, Footbags, & Other Cloth Balls that includes footbag tutorials.

Fabric grain and bias

The orientation of woven fabric's grain (which determines the direction of stretch) on each panel will affect the shape and, possibly, the texture of beanbags. With fabrics like corduroy, it will also affect their appearance. I have done some experimentation with this and added grain orientation diagrams (or at least written suggestions) for most of the designs to help you balance the stretch and appearance of woven fabrics across all the panels when tracing them and assembling the beanbags. The orange peel ball is especially sensitive to grain orientation and I discuss that in that design's chapter.

In general, the fewer panels a design has, the more important the orientation of the fabric's grain on each panel is. **Balancing the grain direction on your beanbags will prevent a lopsided shape**, and will create a balanced visual aesthetic for corduroy or striped fabric.

Stitching patterns versus cutting patterns

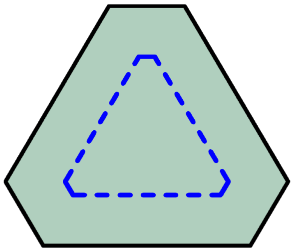
It is important to understand that, unless I say otherwise, when I talk about patterns in this guide I am referring to *stitching* patterns as opposed to *cutting* patterns. If you like to use only a cutting pattern and then stitch just inside the edges of the panels rather than transfer a separate stitching pattern, **read on so that you understand the difference and why the distinction is important**. To make the template, cut out a stitching pattern a little outside the lines and then stitch where the stitching pattern would have been.

You can also draw a cutting pattern. My instructions explain how to draw the cutting patterns, which usually have different proportions or curvature from the stitching patterns in order to maintain a constant margin between the two and result in the stitching pathway having the correct shape. Be sure to use those directions so that you get a well-shaped ball.

If you want to use just one template, however, I recommend making a stitching template and then cutting out the panels a little outside that pattern. **Stitching accuracy is important while cutting accuracy is not, so having lines to sew along is important**.

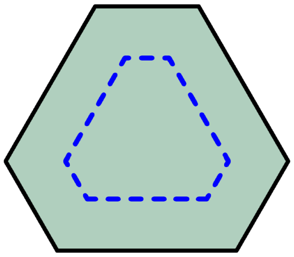
The stitching pattern is what determines the size and shape of the bag and so it is crucial to draw it correctly and sew along it accurately. **The cutting pattern can be anything that provides enough seam allowance** and it has no influence on the bag's size or shape. It doesn't even need to be the same shape as the stitching pattern (though it is helpful for it to be); it could be just a blob. In the end the seam allowance will merely be excess fabric hidden within the bag, and you can also trim it down after sewing the bag, before inverting it.

The reason I use both patterns, and cut out my panels accurately, is that it allows me to align the patterns as I sew by aligning the panel edges. It is not important, but it is helpful. Using a cutting template to draw the patterns also helps with positioning and spacing the patterns on the fabric so I don't need to judge by eye how far to space them to get enough seam allowance on adjacent patterns.



Using a stitching pattern as a cutting pattern will not only result in a smaller than expected bag size, but can change the bag's shape and appearance. This is because by subtracting an equal seam allowance from all sides of the panel, you change the shape and proportions of the panel (in most cases).

The image on the left gives an example of this from the hexagonal panel of the 14-panel Equidistant bag. Because the stitching (the blue, dashed line) is inside the hexagonal pattern instead of along it, the panel has effectively been transformed into a near triangle.



My cutting pattern calculations produce shapes that have different proportions or curvatures from the stitching patterns (where applicable) so as to maintain a constant margin between the two. In the case of the hex panel, the cutting pattern (the outer border in the illustration on the left) would have short sides that are longer in relation to the long sides. The short sides on the stitching pattern are 36.6% the length of the long sides which produces the bag shape I defined, but in the cutting pattern (in my example) they are 57.7%.

Seam Allowance

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Seam allowance is the excess fabric outside the stitching pattern. Its purpose is to allow the raw, fraying edges of the fabric to be hidden within the ball, and to prevent the stitches from popping through the edges. Beanbags are initially assembled inside-out with the seam allowances exposed, and are inverted through the final open seam, and then that seam is closed from the outside. The exception is when you are working with stiff leather or something similar, with the panels assembled edge to edge as on a baseball. In that case there is no seam allowance and the ball is assembled right-side-out, and a different stitching method is used such as the baseball stitch.

But with most materials your panels will need a seam allowance, and it will need to be wide enough to prevent the seams from tearing open when the bag is treated roughly. This is especially important for footbags, and more so if you use a woven fabric. **A wide seam allowance will make the seams more durable**.

For the beanbag structures up to the 14-panel I use 8mm seam allowances because I like to iron the seam allowances flat and this is easier with a wider allowance. For the rest of the structures, or when I do not intend to iron the seams, I use 4mm allowances, which helps make the seam intersections less crowded. 4-5mm is enough allowance to handle the fraying of denim, but I would not want to go any narrower with a fabric like that.

For very narrow seam allowances, some people do not use two templates as I do (one for the stitching pattern and the other for the cutting pattern). They use only a cutting pattern and then stitch just inside that pattern, judging by eye where the stitching should be. If you want to use just one template, though, I recommend making a stitching template and then cutting out the panels a little outside that pattern. **Stitching accuracy is important while cutting accuracy is not**.

Beanbag Roundness and Uniformity

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As I discussed in the "Introduction" chapter, the roundness of a beanbag is important for making juggling (or footbagging) easier and more successful. All of my designs produce approximately spherical bags, but with stiff or non-stretch fabrics, **the designs with fewer than 8 panels can be noticeably non-spherical** due to the degree of stretching required to make such large panels conform to a spherical shape (the panels' curved edges produce circular seams and pleasantly rounded corners, though, unlike true polyhedral beanbags).

While the **mild angularity across the seams** of the orange peel ball, tetrahedron, and cube is not enough to greatly affect jugglability, for me it **makes those designs less appealing** because I like the look and feel of a perfect sphere. This is something to consider when choosing a design to make. If you use a stretchy fabric for these designs and fill it tightly, you could probably get perfect spheres. I use denim and corduroy, which work well and stretch a little, but not quite enough. With stiff, non-stretch fabrics, **filling the bags loosely helps make them feel rounder** because they can conform to your grip. But I have found that the best solution is to **press the finished and filled ball against a hot iron along all the seams, which can reshape even the tetrahedron and cube into nearly perfect spheres**.

My tetrahedron, cube, and octahedron designs use faces having curved edges, which is the only way those polyhedra can approximate spheres. My 12 and 14-panel designs also use curved panel edges, but the curves are not as important for those designs, especially for the platonic dodecahedron. The bags are nearly round anyway due to the number of panels, the bluntness of the vertices, and the flexible nature of cloth. The 24 through 32-panel designs do not need curves at all.

Uniformity, meaning a dense, consistently-spaced network of seams and panel faces that makes the surface of the bag look and feel the same from any angle, is, to me, **important mostly for tactile aesthetics and somewhat for visual**. This is less of an issue with thin or very flexible fabrics because the seams can't be felt as much. Denim and other thick, dense fabrics will produce very prominent seams.

The more panels a bag has, the more spherical it will be and, in most cases, the more uniform it will feel. So, the 4-panel orange peel ball is the least round and least uniform of the designs in this document, followed by the 4-panel tetrahedron, the 6-panel cube, and the 2-panel baseball. The orange peel ball's seams all run in the same direction and meet at two "poles", and, having only four panels, it will feel a bit angular around the equator. Its advantage, along with the tetrahedron, is that it is quick and simple to make. An orange peel ball with more panels is more spherical, but still not very uniform. It looks and feels different, and will stretch differently, at the poles than around the equator.

The baseball, while a bit angular in places, has a compound seam curvature that gives a better impression of a sphere and provides better seam uniformity. The octahedron (eight panels) is much more spherical and feels more uniform because of the greater number of panels and the addition of a latitudinal seam around what would be the equator of the 4-panel orange peel ball. The cube, with six panels and a combination of horizontal and vertical seams, has roughly the roundness of the 4-panel orange peel ball and a seam uniformity about in the middle between the orange peel ball and the octahedron. It is a good design and I like the feel and look of it.

The high panel count structures have dense networks of seams and are very spherical and uniform even without using a stretchy fabric, but they are also more difficult and tedious to make. **The octahedron**

has the best balance between roundness and uniformity, and ease of manufacturing. It feels almost perfectly spherical with any fabric type.

Fabric

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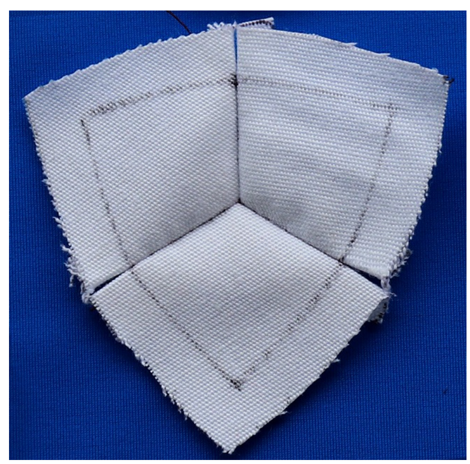
Fabric attributes to consider

Choose a fabric that is **long-wearing and can take some abuse** without bursting at the seams or tearing, has the amount of **thickness, stretch, and flexibility** you want, has good **traction** against your hand or shoe, and has a **pleasant feel** (if it's for juggling). Also, consider **washability** of the fabric if that is important to you. For juggling bags, thick, non-stretch fabrics will produce a firm, rugged feel while elastic fabrics will produce a squashy texture like a stress reliever ball. For footbags, thin, flexible fabrics will produce floppy bags for easier stalling while stiffer fabrics will help them hold a round shape and have a more springy responsiveness to kicks.

When selecting colors, take into account the **color arrangements** possible in the design you intend to make, and ease of **visibility** for you and, if applicable, your audience. I have found that more than two contrasting or clashing colors in a beanbag can sometimes be too busy rather than attractive, so consider your aesthetic tastes when choosing a color arrangement.

Depending on the type of fabric, it may be good to **wash and dry new fabric to preshrink it and remove excess dye** before making it into beanbags. Some of my colored beanbag panels bled into the adjacent white panels when I wet them and so I washed the denim to (hopefully) prevent that on future bags. I have also seen advice to press the fabric after washing it.



The "White Target" fabric I use to test patterns

For testing new panel shapes, you need a fabric that provides good design feedback, accurately manifesting the effects of the panel shape on the shape of the resulting ball. Woven fabrics, especially loosely woven, do not stretch uniformly and so can greatly alter the ball's shape, especially in low panel-count designs. Flimsy or stretchy fabrics distort too easily to effectively test a pattern. A fabric that is too thick and stiff won't bend well at the seam allowances and will cause lumps and distortions in the ball.

For my design testing I use a fabric called **"White Target"** which I found in Jo-Ann Fabric's sportswear section (item #16734915). It is moderately stiff, tightly-woven, fairly thin, and non-stretch. It does still have some bias effect, though. I used a **thick and sturdy felt** for further testing on some of the designs. **Marine vinyl** can be used as a substitute for stiff leather for testing. I discuss this topic in more detail near the beginning of Chapter 5.

Professional choices for juggling bags and footbags

Juggling bags are usually made of **suede leather**, **Ultrasuede** or **Ultraleather (synthetic leathers)**, or **PU (polyurethane) or vinyl-coated fabric**. Footbags are usually made of **Ultrasuede** (especially the **Light or "LT" variety**, which is sometimes referred to as "facile"). My old Jugglebug bags appear to be made of **duck canvas**. That **would be a good choice for outdoor use** as it is very sturdy, won't hold much dirt and debris, and is washable. Corn hole bags are usually made with duck canvas.

As far as I can find out, Ultrasuede, which is quite expensive ($40 – $96/yd. depending on the type as of 2021), can only be purchased on the internet. Stores like Jo-Ann Fabrics and Hancock Fabrics do not sell it. There may be high-end specialty stores that sell it, but I haven't found them yet in my area. A few footbag stitchers have recommended **Field's Fabrics as a supplier of Ultrasuede and Ultraleather**: www.fieldsfabricsonline.com/. This store has brick-and-mortar locations only in Michigan, but their web store is very extensive.

If you use real leather be warned that it may, depending on its thickness, be very difficult to sew with a standard needle and thread and may even require special tools such as an awl, and special thread and stitching techniques. I have not sewn leather, but I suspect even thin leather is tougher than denim to get a needle through.

My choices, and other options (for juggling bags)

I originally used **denim** from sacrificed jeans. You can find very colorful jeans in the women's section of a thrift store. I now prefer **corduroy** because of its pleasant texture and elegant appearance, its greater flexibility, and its better traction against my hands. I also get my corduroy from **sacrificed thrift store trousers**.

I use this source of denim and corduroy because the fabric stores I've been to carry a poor selection of the colors I like for juggling bags, and the fabric they carry is thinner and has a looser weave than that used for most clothing. I value durability in my materials, and flimsy, loosely woven fabrics are also difficult to sew with any precision. **Be aware that different trousers use different types of denim or corduroy, and many use an elastic variety,** and so if you don't choose carefully, each bag in your set, or even each panel, may feel different, be stretchier, or have other differing characteristics.

In Dec., 2022 I bought a new fabric from Jo-Ann Fabrics that I think will work well. It is in the **upholstery section** and is called **Signature Series Multi Purpose Faux Suede Decor Fabric 58″** (item # 07951130 for red). Unlike the faux suedes made for apparel, it is thick and nearly non-stretch and feels tough and durable. It is available in many beautiful colors and is not terribly expensive ($20 per yard).

I used a material called **marine vinyl** to make a couple balls for outdoor games of catch that would feel similar to a baseball, but could be filled with pellets for a lighter, softer impact on the hand. The marine vinyl is 1mm thick, has a leather-like texture and surface traction on the front face, and is similar to leather in its stiffness, stretch, and compressibility. They turned out well and are quite durable. We have used my two-piece ball for several games of catch, including over asphalt pavement, and the ball has held up with hardly a blemish even after hitting the road many times at high speed. Be aware that some marine vinyls may be less durable than mine. I get mine from Jo-Ann Fabrics.

A very thick and stiff, leather-like material like this is best assembled edge to edge with a baseball stitch rather than inside-out with a seam allowance. This type of material will not only make inverting the bag very difficult, but the folding and puckering of the seam allowances will produce a lumpy and misshapen ball (I tried it). Stretching the ball out tightly with filler doesn't help much.

Some women whose blogs I've read enjoy using **random scraps of fabric or old garments** to make patchwork balls for babies to play with (they make them larger than juggling size – sometimes as large as nine inches in diameter). I show examples of these in Appendix I. Consider using interfacing to reinforce or stiffen an overly thin or stretchy fabric. I have no experience with interfacing so I can't say much about it.

Thread

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Choose a strong, durable thread that can withstand the wear and impact that juggling bags and especially footbags sustain. The monofilament thread I use (Gütermann brand "Invisible", Col. 111), or nylon upholstery thread (which I use for marine vinyl balls that have exposed stitching), shoe thread, or at least a heavy-duty, all-purpose thread would be good choices. One manufacturer stated on his website that he uses a thread made for sewing parachutes. Peter Billam in his article *How to Make Leather Juggling Balls*[15] recommends waxed thread for leather. To increase the strength of your stitches, double the thread.

In the early days of my hobby I used a standard, general-purpose thread and I tried to pick a neutral color like gray that would blend as well as possible with the variously colored panels of my beanbags in case it peeked out. This had two drawbacks: 1) It did not blend very well and where the stitches peeked out, they looked a bit tacky; 2) It tended to fray and break during sewing a couple times per beanbag even though it was a good quality thread and I doubled it (I was making my beanbags with denim and pulling the stitches very tight).

For thick fabric, or when I don't want the stitching to show, I now use the **monofilament thread mentioned above called "Invisible"**. It is made of a single, transparent strand like fishing line. It is stronger judging by how much harder it is to break, and there is no risk of running my needle through the fibers of the thread when I make a retreating stitch (I use the backstitch), which frays and weakens it and sometimes caused it to break in my early bags. Strength is important if you use a thick, stiff fabric like denim and, like me, want to pull the stitches tight enough that they won't show. I do not even need to double the monofilament thread to use it with denim.

The monofilament thread is indeed invisible except when the light glints off its glossy surface. One drawback is that it is springy and therefore harder to manage, but it's not too bad. Being nearly invisible, it is also difficult to see my previous stitches and make my backstitches pass through the same points. However, its slick surface makes it easier to pull out stitches when needed, and makes stitches easier to tighten from the outside using my technique of pulling on the stitches ahead of the loose point (see "Tips on finishing the bag"), though this also means stitches will more easily loosen on their own.

If you use an opaque thread, it might be a good strategy to pick a color that, rather than ineptly camouflaging with the panels, will contrast boldly and attractively with them such as black for light fabrics, orange for dark fabrics, blue for red fabric, etc. I haven't tried this, but it may look better than a bland gray peeking out.

15 ~~http://www.pjb.com.au/jug/leatherballs.html~~ [no longer available, except in my online resources archive on my computer]

Template Material

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To make my templates I use a thick, rigid material that will allow me to hold it against the fabric and trace around it without the marker easily slipping under or over the edge, or damaging the corners. I often use a **hard cardboard** (or even index cards or file folders, but they're a bit thin and lack durability). Many kinds of product packaging such as cereal and snack boxes and clothing inserts use cardboard and sometimes plastic that can be used for templates, so plan ahead and save those. Corrugated cardboard is no good – you need something solid and dense.

For greater durability, or for when I intend to use a template long-term, I use **template plastic** I bought from Jo-Ann Fabrics. This plastic is translucent, textured for easy marking, flexible, and easy to cut. **Plastic works better when making Stencil or Combo type templates, and especially with narrow Combo seam allowances.** With plastic, the inside cutouts and narrow areas are easier to cut out without damaging the template or leaving frayed bits behind at the inside corners. I recommend a thick variety like I have if you can find it because it will be easier to trace around and is less flexible, which will help it stay flush with the fabric so the marker tip doesn't slip underneath it. Mine is about **0.5mm/20mil thick**. It is probably **Dritz 3115 Plastic Heavy Duty Quilting Template**.

Filler and Beanbag Weight

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Summary

Weight is important for any juggling object because it will help the object to settle firmly into your hand when you catch it rather than bounce off. This is an important consideration when selecting a filler. Natural fillers have a good weight to them while Poly-Pellets are much lighter. **I use Poly-Pellets supplemented with steel BBs** or small electronics screws to give the beanbags a better weight. (To research the weight of professional beanbags, look up products in the size you want using my list of juggling beanbag and footbag manufacturers in Appendix IV. Many, if not all, products specify their weight, and often the type of filler used.)

Another important consideration for filler is its **durability**. Some fillers will crumble over time, and organic fillers will be harmed by moisture. A third consideration is the **texture** of the filler. **Crushed walnut shell** is gritty and does not flow well, resulting in a stiff, crunchy bag. Smooth-shaped fillers like **flaxseed**, **millet**, or **Poly-Pellets** will allow the bag to conform better to your hand and have a softer, squashier texture.

Footbags, being small and only partly filled, do not contain much filler, and so are usually filled with something heavy such as **sand or BBs**. **I recommend *not* using lead (due to the toxic dust that might leak out) or anything that will rust.** There is more info on this under the "Metal filler options" and "Filler and weight for footbags" topic headers.

Filler and weight for juggling bags

Peter Billam, in his web article *How to Make Leather Juggling Balls*[16], says the following about juggling bag filler:

16 ~~http://www.pjb.com.au/jug/leatherballs.html~~ [now only available on the Internet Archive: http://web.archive.org/web/20231105094249/https://pjb.com.au/jug/leatherballs.html]

> For filling, birdseed (unhulled) millet is commonly used, though the seeds slowly crumble making the ball gradually softer; also, some people are allergic to millet. Sesame seeds are longer-lasting, but linseed [aka flaxseed] is the best of the seeds. Crushed walnut shell is still more hard-wearing and moisture-resistant; it is sold in pet stores as “bedding” for birds and hamsters, and is also used in place of sand as an abrasive for sand-blasting. Rice is too heavy and is not durable. Plastic pellets are completely moisture-resistant, but I prefer juggling with the feel of the natural materials.

Another juggling bag tutorial[17] recommends flaxseed for its weight, and also suggests adding dried lavender or other herbs to add a pleasant smell. If you want scented juggling bags, though, I would recommend using essential oils so that you can renew the fragrance when it fades.

Organic fillers are vulnerable to water. I had a set of juggling bags filled with crushed walnut shell and one of them unintentionally went through the washer. It came out permanently swollen. Organic fillers are also susceptible to mold, and seeds may grow if they get wet. This means you must neither wash them nor drop them into a puddle. **Organic fillers do have a pleasant smell**, however.

Poly-Pellets bag photo from https://www.amazon.com/Fairfield-PP2B-Poly-Pellets-Weighted-Stuffing/dp/B0077AQ0W8. Detail photo from http://www.elizabethsupplies.com/shop/polly-pellets-1kg/

To avoid the problems of water damage and crumbling with use, I primarily use an artificial filler called Poly-Pellets (the product I buy is made by Fairfield, but there are other manufacturers). These are polypropylene (plastic) pellets made for weighted blankets and poseable dolls which I buy in two-pound bags from Jo-Ann Fabrics (they are also available in 1.5 and 6-pound bags). Poly-Pellets are smooth, rounded, inexpensive, and have a good feel to them in a beanbag. They are larger than millet (3 – 4mm at their largest dimension) and so don’t have quite as smooth a texture. You can order various types of plastic pellets in bulk from www.victorypellets.com/.

Poly-Pellets produce a somewhat lightweight beanbag compared to the professional beanbags I have encountered. My tightly filled 2⅝″ beanbags weigh, on average, 3.4oz (96g) while the high-end professional bags of the same size I looked up weigh 4.1 – 4.8oz (115 – 136g).

I liked the extra weight of a set of professional bags I once borrowed. They landed more solidly and securely in my hands and felt less toy-like. I experimented with a heavier weight in my own bags by **replacing some of the plastic filler with copper-coated steel air gun BBs** I found in a closet. After a few trials I found that **I preferred 122.5g (4.3oz) for the 2⅝″ bags** I was using at that time (that was a midway point between a weight I felt was too low and one that was too high).

I juggle only up to three (and sometimes four) balls, though. For numbers juggling a lighter and smaller bag would probably be preferable. The Juggling Store’s website says their research has determined that **80g for a 2.3″ bag is the ideal weight and size for numbers juggling**[18]. I made a set of 2.3” bags for my sister (photo in the next section) and weighted them to 80g, and that was indeed an excellent size and weight. I also made a set of pocket-sized, **2″ bags and weighted them to 75g** which makes this small size very juggleable (there is also a photo of these in the next section). 80g also worked well, but I didn’t feel the need for quite that much weight.

17 “Juggling Balls: a step by step sewing pattern” – http://juggleballs.amielmartin.com/

18 http://www.jugglingstore.com/fusion-beanbagfusion-beanbag-782.html [site no longer exists]

I have some crushed walnut shell and it weighs 6.32oz (179.28g) per cup, settled (unsettled it weighed 5.68oz). This is about 30% heavier than Poly-Pellets which would make my 2⅝″ beanbags 4.41oz (125.02g), only slightly over the weight I found to be ideal for me. I do not like its texture, though.

High-density polyethylene (HDPE) pellets are slightly heavier than polypropylene. You can order them at www.craftpellets.com/. CraftPellets.com reports that their pellets weigh 5.12oz. per cup. My Poly-Pellets weigh 4.87oz., settled (unsettled they weigh 4.48oz.). This makes the HDPE 5% heavier. This agrees with the research I've done on the density of plastics[19]. So, **HDPE won't increase your beanbag weight by much.**

HDPE pellets photo (cropped) from https://www.craftpellets.com/

Both VictoryPellets and CraftPellets sell **extra heavy plastic pellets that have talc to increase their weight** to 9 – 10oz. per cup. That would probably be **much too heavy to be used alone**. You could mix it with the lighter pellets, though.

Mighty Pellets photo (cropped) from https://www.craftpellets.com/

If you mix fillers of two very different weights, **make sure the two fillers are evenly distributed so the bag is balanced**. My 2" beanbags wobble in the air when I spin them in certain orientations. I don't know if I failed to distribute the BBs well enough, or if they gathered together on their own.

If you don't mind using organic fillers, **seeds and crushed walnut shell will probably be heavy enough without metallic supplements**.

Metal filler options

For a metal filler, you can use steel air gun BBs as I do, or you can try searching the internet for suppliers of "stainless steel shot" or "stainless steel tumbler media". Pick a type that is very small and has only rounded shot (some tumbler media have a mix of rounded and various angular or pointy shapes). Some footbag stitchers obtain their metal filler by **emptying out shotgun shells**. One footbag forum contributor recommended **cut wire shot** as a metal filler and provided a link to a supplier: pelletsllc.com/cut-wire-shot. Another recommended using **small electronics screws** (for those who like to disassemble devices and have accumulated screws for which they have no use). I tried this for my sister's juggling bags and they worked well. A reader of my guide highly recommends #6 stainless steel shot from Ballistic Products, which he combines with plastic BBs for optimal weight.

I recommend *not* using lead (due to the toxic dust that might leak out) or anything that will rust. The reader of my guide mentioned above told me that the lead filler he used before switching to stainless steel caused staining on the outside of the white corduroy he used for a footbag, so it was likely getting onto his hands, as well.

19 See http://www.stelray.com/density_val.htm for one of my sources

Filler and weight for footbags

Footbags usually weigh 40 – 65g according to Wikipedia[20] and my own research, and the official rules of footbag sports states that the weight must be in the range 20 – 70g[21]. You will probably need **metal**, **sand**, **fine gravel**, or **extra heavy plastic pellets**, as standard poly-pellets will not provide much weight for such a small and under-filled bag. Footbags are commonly filled with sand, or sometimes metal BBs. One footbag stitcher uses a **mix of Airsoft BBs and metal BBs**[22].

Exercise bags

You could make **heavyweight juggling bags for upper-body aerobic workouts, perhaps as part of a "joggling" routine**, by filling them primarily or purely with metal shot, sand, or fine pea gravel. Make sure you use durable fabric, thread, and stitching if you use a heavy filler. I have not tried this, so I can't say much about it. I have read that **juggling with very heavy objects long term can cause repetitive stress injury to the wrists**, so research that issue if you want to do that regularly.

If you want to make an exercise ball, consider using an actual ball rather than a bag for better durability. You can just cut a small slit in a street hockey ball, tennis ball, racquet ball or similar and fill it with metal shot, sand, pebbles, or even pennies and then glue it shut. To add color and traction to a tennis ball, I saw advice to stretch two balloons over it in opposite directions (the second covers the opening of the first).

Other filler ideas

During my various web researches I came across the suggestion of **making cloth balls that children can throw around the house without breaking anything by filling them with something lightweight**. One woman filled hers with **shredded fabric scraps** from her sewing projects. You could also use cotton or polyester pillow stuffing (a. k. a., **fiberfill**). For a more juggleable weight that will still reduce the risk of overturned lamps, you could fill the bags with a **mix of fiberfill and pellets**.

Some women **add rattles or bells inside the bags for babies**. They often make them larger than juggling size – sometimes as large as 9 inches in diameter. That size would also make a good indoor kick ball.

Flying Clipper, "The world's leading designer of high-quality handmade footbags & juggle balls", uses two isolated fillers for their "Hybrid" juggling bags: a heavy filler (crushed rock) between two layers of shell material in each panel and a lighter filler (plastic pellets) within the bag itself. According to Flying Clipper, concentrating the weight in the outside of the bag and not allowing it to mix with the interior filler results in more predictable flight. Filling a bag with fiber fill but using a heavy filler in the shell is another way to make a ball soft for indoor throwing by children and yet heavy enough to juggle.

I imagine a good way to do this would be to cut panels smaller than the stitching pattern (so they don't hide your stitching lines) out of a thin fabric like interfacing, lay the main panels front side down on a hard surface (prior to assembly), and glue the edges of the interfacing panels to the backs of the main panels with a small amount of heavy filler in between. The glue would need to be flexible so the panels

20 http://en.wikipedia.org/wiki/Footbag

21 http://www.footbag.org/rules/chapter/100

22 https://www.reddit.com/r/footbag/comments/eyt29j/my_experiments_in_footbag_making/

do not become stiff. The hard surface would ensure that the main panels are not warped around the filler. The interfacing panels should be the ones that form a bag. The main panels should be flat.

Another way would be to cut both sets of panels the same size and simply sew each pair of dual-layer panels together. Before you close the last seam of each panel, fill the pocket between the layers with the filler. This would cause the panels to pillow out a bit, though.

Beanbag Size

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I provide printable measuring tapes in the last section of this chapter for measuring your beanbags.

Common sizes for juggling beanbags

2⅝″ and ⅛″ on either side of that are the most common sizes for juggling beanbags from what I have seen at stores, and **2½″ and 2⅝″ fit my moderately large hands very well** for juggling up to four bags (the maximum I can juggle) with a combination of standard catches and “clawing” (catching with palms down, which is easier with smaller objects). For reference, a tennis ball is about 2⅝″ and a baseball is slightly over 2⅞″. Some people prefer much smaller sizes for juggling large numbers of balls or for a better fit in small hands, and some like to use extra large sizes for stage performances.

The Juggling Store’s website says that their research has determined **2.3″ to be “ideal for those with smaller hands and a great choice for numbers juggling”**[23]. For reference, a racquet ball is 2.25″. When my sister asked for juggling bags, she requested the 2.3″ size (shown on the right, in my hand), which she thought would fit her smaller hands better than my juggling bags. She was very happy with that size, and even I found I liked that size, though I still prefer 2.5″.

My homemade 2.3″ juggling beanbags

Each instructional chapter includes ready-to-print patterns for sizes from 2″ – 3″ in ¼″ increments, and most also have a 7″ pattern designed for a wide range of scaling. For those who want to draw their own pattern, each chapter has a table of pre-calculated pattern dimensions for every ⅛″ increment from 1¾″ to 3″, and also the formulas necessary to calculate your pattern size for any desired diameter. 2.3″ is a little larger than 2¼″ (2.25″) and a little smaller than 2⅜″ (2.375″) (the difference in circumference is -4mm and +6mm, respectively), so if you want that exact size, you’ll have to calculate your own pattern size, or print my pre-made 2.5″ pattern at 92% scaling.

When choosing a size, consider that while a ⅛″ (3.175mm) difference in diameter may not sound significant, your grip is around the circumference and your grip changes by *pi* (3.14) times the change in diameter. The difference of over ⅜″ (9.975mm) in circumference makes a small but noticeable difference in how the bag fits in the hand.

The influence of weight versus size

The previous section, “Filler and Beanbag Weight”, discusses the weight aspect of juggling bags. **Weight makes a great difference in how juggleable a particular size is**. I used to think 2½″ was my favorite size, but when I later made 2⅝″ beanbags, I found I preferred that size. Years later when I

23 http://www.jugglingstore.com/fusion-beanbagfusion-beanbag-782.html [site no longer exists] experimented with adding heavy filler to the bags, I realized that **the reason I preferred the larger size was because it was heavier**. I was using light-weight plastic pellets as filler, which made the bags lighter than they should be, ideally. Now that I am adding metal filler to the plastic to raise the weight, I am back to preferring 2½″.

When I made the 2.3″ bags for my sister, I weighted them to 80g with metal added to the plastic filler and I was surprised by how much I liked that small size. That was how I discovered that I actually prefer a smaller size than 2⅝″, as long as it is heavy enough.

I even made a set of three 2″ bags using the octahedron design to carry in my pocket when I feel the desire. Normally this size would be too small and light to juggle well, but after filling them loosely with plastic pellets, **I increased their weight to 75g using steel BBs**. With that weight they land solidly and securely in my hands and are very juggleable. Filled more loosely still, they would also work well as footbags.

My homemade 2″ pocketable juggling beanbags

Common sizes for footbags

As for footbag sizing, footbag.org states that freestyle footbags are halfway between the size of a golf ball and a baseball (1.68″ and ~2.9″), which would be roughly 2.29″. Most of Bomb Footbags' and Flying Clipper's products fit this description at around 2.25″ while most of HaniaBAG's products are only 2″ and under. My Sipa-Sipa crocheted footbags are 2″. To research the size of professional beanbags, use my list of juggling beanbag and footbag manufacturers in Appendix IV. Footbags are made with gathered seams, but my patterns do not account for this. So **to achieve a desired size with gathered seams, try a pattern size about ½″ or 25% larger than your target size**.

Controlling a beanbag's size during manufacturing

Size will be affected by the type of fabric, your sewing practices, and how firmly you fill the bags. If you use a material that has a different thickness or stretch from corduroy or do not fill the bags as firmly as I do, your bags may end up being a noticeably different size than I claim they will be and so you may want to adjust the template size a bit.

For high panel-count structures, if you are particular about the size of your finished beanbag, **you must be very precise in drawing and cutting out your templates, and in sewing along the lines**. It is also important to **sew on the correct side of the lines**, especially if you use a thick marker for the pattern. For exterior templates, sew on the inside of the lines, which is where the edges of the template were. For stencil (interior) templates, sew on the outside of the lines. **The large number of panels means a tiny change in size in the template or stitching path amounts to a large difference in beanbag circumference.**

Also, I pull my stitches pretty tight (though not tight enough to warp the fabric). Loose stitching will increase the beanbag's size. **Gathering the seams**, which is common for footbags, **will (I think) reduce the size drastically**.

You may need to do some trial and error to determine the best fit for your hands and juggling or footbagging practices. It is a good idea in any case to assume your first bag is a practice bag. If you are as much a perfectionist as I am, you'll find that it takes some experience to make these things right.

Measuring your beanbags

The easiest way to measure your bag's finished size (if you don't have a dressmaker's tape measure) is to wrap a strip of paper around it, mark the overlap point, measure the strip up to the mark, and then divide by *pi* (3.1416) if you want the diameter.

To make the paper strip more reusable and convenient, you can mark a small range of measurements on it with the help of a ruler so you don't need to mark and measure it each time you use it. That is what I always did. For the Second Edition guide I created **printable measuring tapes**, including ones that effectively divide by *pi* for you. They are in the last section of this chapter.

To help ensure a correct measurement, since beanbags are not perfect spheres, **measure the bag a few times in different directions** and calculate an average circumference. Note that the lower panel count structures have different circumferences depending on how they are measured. The 4-panel orange peel ball, for example, will be larger along its seams than between them (except with a fabric stretchy enough to become spherical). I ignore this in sizing my beanbags and I measure only between the seams, but you might want to adjust for the larger seam circumference.

Adjusting/Scaling a Pattern to Produce an Accurate Ball Size

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I provide printable measuring tapes in the last section of this chapter so that you can measure your beanbags and calculate the pattern adjustment factor.

The need for a pattern adjustment factor

The formulas I provide in each instructional chapter to calculate pattern sizes (and which I used to size the ready-to-print patterns and populate the tables of pattern measurements) only express the **polyhedron size** as if you were going to place the stitching patterns edge to edge and construct a rigid model. **The actual stitched and filled fabric bag will probably be significantly larger or smaller** than this. The size of the finished beanbag will be influenced by your fabric choice, stitching practices, and how tightly you fill the bags.

I used the formulas in conjunction with an adjustment factor that accounts for the measurements I took of each of my corduroy beanbags. The tables of pre-calculated pattern measurements include both the Base polyhedron values and the Adjusted values. The adjustment factors used for each design are given in their respective chapters.

The difference between the mathematical calculation and the actual beanbag size is important to account for because a mere 5% amounts to one full centimeter (0.4″) of circumference in a tennis ball sized bag, which makes a noticeable difference in how well your hand can wrap around it. Beanbags can easily vary by that much or more from the mathematical prediction.

My original denim bags were larger than the template calculations by 0.8 – 9.5% (depending on the design and how firmly I filled it), except for the highest panel count designs which ended up *smaller* by 2.24 – 4% unless I filled them tightly. The corduroy bags are always larger, but by a smaller percentage in the high panel count designs.

There are two reasons that I can see for this varying change in size. First, denim stretches somewhat when tightly filled, which will increase the size of low panel-count designs. Second, its stiffness and density cause the folding at the seams to consume some of the panels' width, making the bags smaller for higher panel-count designs. I assume this is why the high panel count bags ended up smaller than the predicted size: they have a lot of seams.

The corduroy is also thick, but it is much softer and more loosely woven than the denim, and so it folds and compresses much more easily. The seams of my denim 32-panel bag are very prominent while the seams of the corduroy one are subtle, meaning the fabric is folding more sharply, and thus not as much of the panels' size is being consumed by the folds. There was a 5.3% difference in size between my denim and corduroy 32-panel bags.

Calculating your own adjustment factor

If you need to figure out your own adjustment factor to allow for gathered seams, elastic fabric, or other factors, first either use the one I provide for the design you're making, or, if you are using my tables of pattern measurements or sizing formulas, you can make your best guess at the adjustment and substitute it for mine (or don't use one at all). Then:

1. **Create your templates and record the expected/nominal ball size they produce** (that is, the ball size indicated on the pattern you printed or in the pattern measurement table if you used that, or the ball size you used in the formulas if you calculated the pattern yourself).
2. **Once you have made a beanbag, filled it to your preferred firmness, and kneaded it a bit to stretch it out, measure it.** Instructions for measuring beanbags are at the end of the previous section under the topic header, "Measuring your beanbags".
3. **Divide the actual ball size by the expected/nominal size and the result is your adjustment factor**. When the ball is larger, the adjustment factor is greater than 1. When it is smaller, the adjustment factor is less than 1.

Once you have your adjustment factor, or a guess at one, refer to the appropriate subsection below to use it to resize the pattern and hopefully produce your target beanbag size.

Though I have never gathered my seams, I expect this will shrink the bag by a lot, and so, especially if you are making a footbag, you should probably use a large, negative, initial adjustment factor (significantly less than 1), increasing the pattern size so your bag does not end up so small it is hard to measure. I suggest around 0.8 (meaning you expect the finished bag to be 20% smaller), based on a tutorial from Ivan Builds, the patterns he uses, and the ball size produced by them. To simplify this when using my ready-to-print patterns, just select a couple sizes larger than your target size, and that should be pretty close. Hopefully you have enough experience with gathered seams to know what effect this has on the finished product. Both the Ivan Builds video and this tutorial from Umbrella Footbags shows how to make a footbag with gathered seams: https://umbrellabags.wordpress.com/stitching-tutorial/.

Scaling my ready-to-print patterns

Your PDF viewer's print dialog should allow you to scale the pattern printout by a percentage. **To calculate the scaling percentage, divide 100 by the adjustment factor**. If, for instance you originally chose the 2.5″ pattern but the beanbag ended up being 2.25″, your adjustment factor would be **0.9**.
100 ÷ **0.9** = 111.11%.

If scaling up the pattern prevents it from fitting on the page, you can **scale up or down a larger size instead**. First, divide the pattern's expected size (the diameter marked on the pattern) by the adjustment factor. Dividing 2.5″ by **0.9** yields 2.78″. That is the pattern size you need for your next bag. Since this happens to be close to 2.75, you could simply use my 2 ¾″ pattern and get a nearly correct size. To scale a larger pattern to this size, just divide the target pattern size (2.78″) by the pattern size you wish to scale, and multiply the result by 100 to get the percentage. To scale down the 3″ pattern, for example, divide 2.78 by 3, yielding 0.9267, multiply it by 100 to get 92.67, and use 92.67% in your print scaling. To scale up the 2 ¾″ pattern, divide 2.78 by 2.75, yielding 1.0109, and multiply it by 100 to get 101.09%.

Adjusting the values in my pre-calculated pattern measurement tables

Take the pattern measurement values you used previously (note whether you used the Base values or the Adjusted values), divide them by your adjustment factor, and use the resulting values to draw your new pattern. That should produce the correct beanbag size.

Applying the adjustment factor to the pattern sizing formulas

My sizing formulas have an adjustment factor already (in orange font). If you used that one before, multiply it by the adjustment factor you calculated from your actual beanbag measurement and then recalculate the pattern dimensions using that new adjustment factor. If you did not use the default one, simply use yours in the formula.

Making Templates

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Precision in drawing and cutting out templates is important. If there is a significant error, you may find that the stitching lines on two panels you are sewing together don't match up, or there may be some imperfections in the shape of the bag, and the bag may be slightly larger or smaller than you expected (**this is especially true for the designs with high panel counts** because any error is compounded several times).

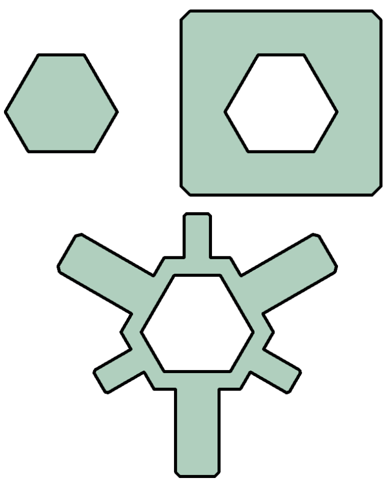
If you want to draw your own patterns and are computer literate, I recommend the free computer application called SketchUp Make which will allow you to draw and print the templates with perfect precision. I discuss it in the next chapter. Otherwise, it's ruler, pencil, compass, and protractor.

My method of making templates is first to draw or print the design on paper and then attach the portion of the paper with the design to the template material with adhesive tape (double-sided works best for patterns with curved edges because it keeps the paper and template material aligned when they flex as you work the scissors around the curves). A glue stick would also work. Then I cut it out. Drawing the design on paper prevents wasted template material if I make a mistake, and using paper first, even when printing the pattern, also allows me to position the shape closer to the edge of the template sheet which conserves my template material.

Types of templates

I make both a stitching template and a cutting template because I use wide seam allowances, and I want to cut my panels accurately. I use wide seam allowances because my fabric choices fray a lot, and because, at least for the lower panel-count designs, I like to iron the seam allowances flat to improve the look of the seams, and this is easier with extra allowance. If you don't want or need a wide seam allowance, you would probably need only a stitching template, and then cut the panels out a little beyond that pattern. Using a cutting template to draw the patterns does help with positioning and spacing them on the fabric, though, so you don't need to judge by eye how far to space them to get enough seam allowance on adjacent patterns.

I cut my panels precisely, even though it is not necessary, because it allows me to align the patterns as I sew by aligning the panel edges. Also, when I draw the front stitching lines (used when closing the final opening from outside the bag), it is easier to align the template with the pattern on the back of the panel if I can simply align both with the edges of the panels.



There are three types of templates you can make: the type you trace around, the type you trace within, and a combination of the two, which I'll call the **Exterior**, **Stencil**, and **Combo** types.

The combo type (the bottom one) is only needed if you use both a stitching and a cutting template. If you can stitch or cut accurately without a guide, you don't need it. **The outer edge of the combo template serves as the cutting template**.

The combo template will likely need tabs to hold it down with as shown in the illustration. The tabs will interrupt the cutting pattern, but that won't be a problem since the cutting does not need to be highly accurate. All you really need are the corners of the pattern. The combo template design shown is the one I actually used for my new 32-panel bags and it worked very well. If you use a 4mm allowance as I did, the narrowness of the frame will require a fairly rigid material so that it stays flush against the fabric and does not let the marker slip under it.

The benefit of a stencil or combo template is that **interior tracing is much easier and faster than exterior tracing**, and they are easier than the exterior type to hold down without your fingers getting in the way of the marker.

Adjusting stencil templates for stitching inside the lines

One minor issue with the stencil type template is that, at least when using thick markers, you will need to stitch on the outside of the line since that is where the edge of the template was (stitching on the inside will reduce the size of the beanbag), and this means **the line will not be hidden within the seams**. That is a problem only when the marker has bled through the fabric. But if you use a **Sharpie marker** as I recommend, **it will soak through most light fabrics**.

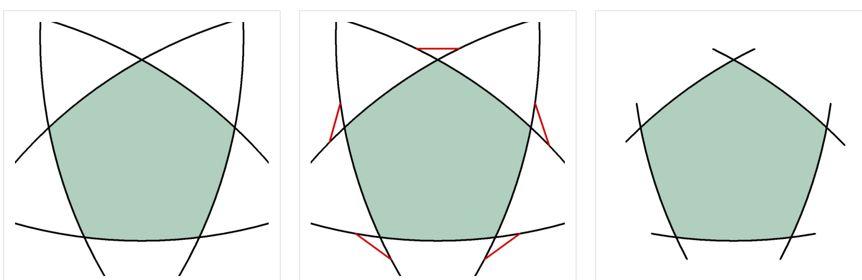
So, to avoid this problem, I recommend that when you cut out the template, you **cut the template's interior slightly outside the lines**, shifting the edges outward by the width of the marker lines. Then the edges of the pattern it produces will be correctly positioned for stitching inside them. Just use the marker and a ruler to draw partial lines against the pattern to serve as a guide for where to position your cuts, and then cut the template on the outside of those marker lines. For combo templates, shift the outer edges by the same amount to maintain the same seam allowance.

Cutting out the templates

Straight-edged patterns can be cut out easily with an X-Acto knife and steel ruler. Curved edges will be more difficult to cut with an X-Acto knife, so you may need to use scissors. However, you will probably not be able to use scissors to cut out interior templates, so I recommend using exterior templates for curved-edge designs. If you want to make a stencil or combo template with curved edges, you can either cut it free-hand with an X-Acto knife if you are skilled enough, or cut the edges with three or more straight cuts that approximate the curve.

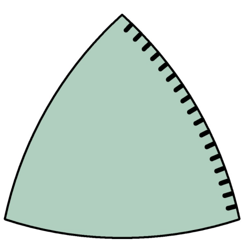
Making curves easier to cut accurately with scissors

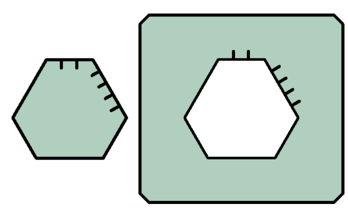
For arcs, especially the very shallow ones for the high panel count designs, I find it helpful to **leave some excess arc beyond the pattern borders to help guide the scissors** as they enter and leave the curve so I get a more accurately curved cut. To do this in SketchUp, draw a line through the arcs a short distance away from the intersections as shown below, separating the arcs into segments that can be erased separately. Then erase the portion of the circles beyond the lines, and then the lines themselves.



How to retain excess arc at each edge of circular patterns to help guide the scissors

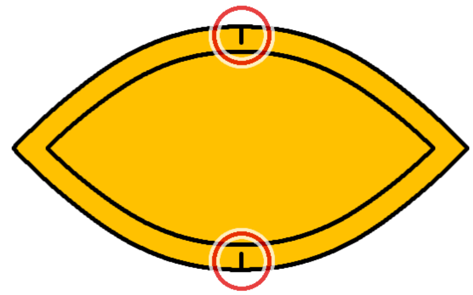
Adding stitch marks and alignment marks to the templates





I have found it very helpful to add stitch marks along one edge (or two adjacent edges in the case of the pentagons and hexagons) which I can then transfer to my front stitching patterns on the panels. **The stitch marks help me keep my stitches made from the outside aligned** so that I do not get skewed seams. Stitching from the outside is difficult and tedious to do right, and this practice makes it much less so. I make my stitch marks 3mm (about ⅛″) apart. Depending on your stitching method you may need different spacing.

Also, for patterns with long edges such as the 4 and 6-panel designs, I **add a mark at the center of each edge** (during the drawing of the pattern) to transfer to each edge of my panels. This gives me a **reference point to help me keep the panels matched up as I sew them together** so I proceed at the same rate on both. With thick fabrics, **one panel tends to compress or stretch more than the other** so that I reach the end of one panel and still have a stitch or two left to make on the other and the corners don't align. My Ready-to-Print patterns have these midway marks.



Add midway marks to each panel edge to help keep long edges aligned while sewing.

Marking the Fabric

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Summary: Ultra-fine point Sharpie marker or standard graphite pencil for light fabrics, correction (white-out) pen for dark fabrics (I use the Pentel Presto!). And remember to trace the patterns onto the back of the fabric (the side that will be inside the bag).

To transfer the stitching patterns onto the fabric, you need a way to mark the fabric that is highly visible, won't rub off or disperse as chalk will do, and that either washes out or is permanent and will not bleed when moistened but will stay hidden on the back/inner side of the panels or within the seam allowance. Do not use a standard ballpoint pen as I did at the beginning years ago because it will likely bleed when wet and make a smudgy stain through the fabric.

The best ways I have found to **mark light-colored fabrics** is with an **ultra-fine point, permanent marker** (e.g., a Sharpie) or a **regular pencil** (I use an automatic one with a 0.9mm lead). The **Sharpie** brand marker I use works well even for medium dark fabrics and **does not bleed** when moistened or scrubbed with soap (I tried it), but it **does soak through the fabric** pretty easily while I am drawing with it because it is such a wet ink. So **for light colored or thin fabrics, be careful to hide it within the seam, or make quick strokes with light pressure**. Don't linger at the corners or you'll get smudges on the other side of the fabric.

Graphite pencils are dark enough to work on most colors and graphite is also somewhat shiny which helps with visibility on darker fabrics. I recommend using a medium or soft lead. **Pencils work well on firm fabrics like denim**, but a soft fabric would tend to fray under the abrasion required to make a good mark. Be aware that while graphite fades somewhat during use, including during stitching (and probably even more if you laundered the bags), as the graphite particles disperse and rub off, it may leave a bit of a stain, so try to hide it within the seams when you sew from the outside.

To mark dark fabric, I found that a correction pen such as the Pentel Presto! is very effective, and so has one other stitcher I encountered on the web[24]. A correction pen is a ballpoint white-out pen, and the liquid paper sits on top of the fabric and is very visible and does not disperse or fade as I sew. It also **does not bleed** when washed. It **does soak through thin fabric** like the Sharpie marker, though.

24 "Custom 'Octohedral' Juggling Bags (or Hacky Sacks)" – https://www.instructables.com/id/Custom-Octohedral-Juggling-Bags-or-hacky-sacks/

One footbag stitcher[25] uses a silver metallic Sharpie marker. There are ultra-fine point varieties of these. I bought a white Sharpie oil-based paint pen and found it to be almost entirely useless. The paint immediately soaks into most fabrics (and paper and cardboard) and all but vanishes. Going over the same line multiple times results in the paint pooling on the surface beneath the fabric, but still not making a useful line on the top of the fabric. I may try other paint pens in the future.

I also saw advice to use old slivers of worn-down bar soap. That has the advantage of washing out. I have not used that method, but I think they would be too thick and imprecise for this kind of work.

You can also buy **special dressmaker's pens and pencils**, but in my limited experience they **do not work very well**. My water-erasable pens made very faint lines, at least on denim. They also dried out sooner than I would have expected. The white dressmaker's pencil I tried made such a faint line on the navy blue denim I was using that I could hardly see it (the white water-erasable pen I used years ago was hardly better). Maybe these pencils work better on other types of fabric.

Remember that if you use a thick marking tool and the size of the bag matters to you, it is important, especially for the high panel count designs, to **sew on the side of the line where the template edge was**, not in the middle, as this may noticeably affect the size of the bag.

To help prevent the pencil or permanent marker lines from showing on the outside of the bag when using thin fabrics, stitch on the inside edge of the stitching lines (which requires the exterior template type, or else a slightly enlarged stencil type). For the front stitching pattern (which you will sew along to close the final seam from outside the bag) sketch the pattern lines a millimeter or two away from the template, positioning them closer to the edge of the panel, and then stitch slightly inside them (toward the center of the panels). These techniques will result in the lines being hidden from view within the seams, even if they bleed through the fabric.

Stitching Techniques

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Summary

- I sew my juggling bags by hand, and, **for normal cloth, I use the Backstitch** (instructions later in this section) to produce **smooth, strong seams**. **For stiff, leather-like materials I use the single-needle baseball stitch** (instructions and tutorial link in the next subsection). **Footbags are sewn with the basic Running Stitch**, which allows the seams to be gathered. I have no experience with gathered seams, so if you need help with that, you will need to find a tutorial. My list of tutorials in the first chapter includes a few footbag tutorials that demonstrate this.
- **Adding retreating stitches** at the ends of each seam, even if you are not using the backstitch, will help pull the corners together and **form tightly closed vertices** on the bag (does not apply to the baseball stitch), as will **stitching each panel corner to the one opposite it** as well as the ones adjacent to it (for 4-way and above intersections).
- **For the sake of accurate sizing, especially for high panel-count designs** or if you use a thick marker for transferring the patterns onto the fabric, it is important to **sew on the inside edge of the stitching lines** (where the edges of the template were), **or on the outside if you use a stencil type template**, so as not to change the size of the bag from what you were expecting. It is also

25 https://www.reddit.com/r/footbag/comments/eyt29j/my_experiments_in_footbag_making/

important to **pull the stitches tight**, though not so tight that they pucker or warp the fabric and distort the shape of the panels.

- **If you have trouble proceeding at the same rate along each of the two panels you are sewing together, or otherwise find that their corners do not align when you reach the end of the seam**, requiring more stitches on one panel to reach the corner than on the other, **make a midway mark on each panel edge to help you keep the panels aligned as you sew**. I illustrate this at the end of the "Making Templates" section.

Alternate method for thick, leather-like materials

The single-needle baseball stitch, closely-spaced and pulled tight, has no leaks, even when tightly stretched as this ball is.

My sewing techniques and many of the other techniques in this document apply to thin, flexible materials. If you use a thick and stiff leather, marine vinyl, or a similar (non-fraying) material, I advise using no seam allowance and **assembling the ball right side out with the panels edge to edge using the baseball stitch.** That was my method for the **marine vinyl balls shown here**, but I use a single-needle version of the baseball stitch. I use **nylon upholstery thread** for these balls. (Note that my "Tips on finishing the bag" subsection a few pages down does apply to this type of construction.)

A thick and stiff material will not only make inverting the bag very difficult, but the folding and puckering of the seam allowances **will produce a lumpy and misshapen ball** (I tried it). This can be mitigated somewhat by filling the bag very tightly, but you will still not get a smooth ball.

Leather juggling ball by EmCouros on Etsy.com

Here is a well-made video tutorial I found that demonstrates both the double and single-needle baseball stitch: 2 Types of Baseball Hand Stitch 101 (Double and Single Needle) by Tords Leather Crafts. I space my stitches 2–3mm from each other, which produces attractive and leak-proof seams. **For real leather, the stitch holes are punched out with an awl, a sparser, double-needle baseball stitch is used, and the ball is laced with thick, waxed thread.** This video demonstrates the process: **DIY Leather juggling ball kit by Maria del Carmen Aboal Fernández.** The photo on the left shows an example of this technique. My patterns up to 12 panels include awl hole marks for use with leather.

In brief, the process is the same as lacing a shoe. The needles always pass up through the material from the underside, then across, down between the two edges of fabric, and then up through the fabric on the other side. The single-needle version I use for marine vinyl produces stitches that are staggered as shown on the right rather than even with each other as they are on the ball above and on baseballs. Try to keep the stitches spaced evenly, both from the edges and from each other.

I begin the thread by tying a surgeon's knot around the edge of a panel at the corner (I do not trust ball knots never to pull through), crossing over to the other side, and then back to the starting point again before proceeding down the seam. I make this extra stitch back to the previous stitch hole at the beginning and end of each seam to produce **pairs of aligned stitches across the seam that pull the corners down flush.** This forms a tiny triangle around 3-way vertices.

Make sure the stitches have enough bite (meaning they pass through the material far enough from the edge) so that they do not tear through the edge when you pull them tight. Marine vinyl requires at least a 2.5mm ($^{3}\!/_{32}$″) bite.

When I finish each seam, or have stitched a few inches, I pause and use a blunt tapestry needle to pull on each stitch starting at the beginning of the seam (or at the last pause point) **to further tighten all the stitches. This keeps the seams tightly closed** even after I have stretched the ball out with filler, and makes them **leak-proof and better-looking**. For polyhedral designs I continue the thread from corner to corner.

You can use a balloon as a liner to hold the filler and prevent leakage (put the body of the balloon into the ball near the end of the assembly, stuff the pellets/seeds into that, then trim off half the neck and tuck the rest into the ball), but **my seams are completely leak-proof the way I sew them and there is no need for a liner**. If you use real leather and punch holes for the stitches, you will want to use a sparser stitch, and that may necessitate a liner.

General tips (for sewing thin, flexible materials that use a seam allowance)

I am not very experienced with sewing and there are many techniques I have not tried. **I use the backstitch, which produces smooth and elegant seams** like the Gballz beanbag on the right, but it is also somewhat slow, at least compared to a running stitch (photos of my own beanbags are in the Introduction chapter under "[The Designs: Discussion and Comparison]").

Some leather beanbags such as the Renegade brand suede beanbags shown here have an attractively rippled seam which I assume uses a sparser stitch and would therefore be much quicker to sew. The Renegades probably use a running stitch (the basic, in and out/back and forth stitch). Footbags are also sewn with the running stitch, which allows the seams to be gathered.

Smooth-seamed Gballz from http://www.gballz.com/ and wavy-seamed Renegade suede balls from http://www.renegadejuggling.com/8-Panel-Suede-Ball-p166.html

For the rippled seams, equally-spaced stitches are important for an attractive appearance. The spacing of the backstitch can be more careless and still produce smooth seams. **For either seam style, it is important to keep the panels aligned during sewing, follow the patterns accurately, and pull the stitches tightly** if you want an elegant, perfectly round bag with no bulges or skews, and with no stitching visible from the outside. **If you pull the stitches so tight that they crinkle or warp the**

fabric, wriggle it straight again so that the finished seams are not distorted (unless you like the puffiness of gathered seams, but it must be done right).

The shorter/more closely spaced the stitches are, the smoother and stronger the seams will be, though the backstitch does not need to be extremely short to produce a smooth seam. **My short stitches (the retreating stitches) are around ⅛″ (3mm) long,** and even that may be smaller than necessary. When I need to restitch a seam (some bag designs' stitching pathways make this nearly unavoidable) I can **make the duplicate stitches twice as long** without a problem.

When stitching from outside the bag (after inverting it), especially for the "Backstitch from the exterior, Approach 2″ farther on in this section, I have found it very helpful to **add marks along the front stitching lines** (before assembly) 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 3mm apart.

Closing seam intersections tightly

Make sure your stitching for each seam reaches the corners of each panel's stitching pattern so that all corners are tightly closed around each of the ball's vertices/seam intersections. This will make the vertices leak-proof and more elegant-looking.

When you add a new panel to a pair you finished sewing together, **make sure the needle enters the new panel at the same point it exited** the panel to which it will be joined **so the corners will line up**. Sometimes this means you will have to enter the new panel a short distance away from the corner and begin with a retreating stitch back to the corner before proceeding down the edge so that the stitching still meets the corner.

There is no need in my opinion to add whip stitches at the seam intersections. Whip stitches can also bunch up the seam allowances and pucker the fabric and make the corners look less elegant. I did this years ago and I have seen advice on the internet to do it, but as long as you stitch accurately, make the stitching all meet at the corners of your stitching patterns, and pull the stitches tight, **there is no more possibility of filler leakage at the corners than anywhere else on the bag**.

The exception is a design like the 6 or 8-panel orange peel ball where many panels come together at the intersections. My 8-panel ball's corners were initially separated as shown on the right and **I had to take special steps to close the intersections tightly**. **Even with 4-way intersections it helps to take a little extra care.**

Here are two suggestions. Method b is more effective, but takes more time. I think you will need to use that method for intersections of more than four seams.

a) **General practice for all designs:** At the end of each seam, make a stitch that reaches the corner of the pattern, then make a short retreating stitch before continuing to the next seam or tying off the thread. This is what you would do for the backstitch, but even if you are not using the backstitch, I think this will help. The retreating stitches **form complete loops of thread through the fabric that will cinch the corners tightly together**.

b) **Technique for 4-way and above vertices:** Instead of stitching each panel tip only to the adjacent ones, **stitch it to the opposite one as well** by passing the needle diagonally through the intersection in both directions to form an X within the intersection. (This can only be done when you have at least four corners attached.) **To do this:**

1. Make a retreating stitch through the two panels you're sewing, away from the intersection you just reached (as in technique "a").
2. Then make an advancing stitch back to the intersection, but this time **pass the needle diagonally through to the opposing panel tip**, right at the corner of the patterns.
3. Make a small stitch down the seam in that quadrant to bring the needle a short distance away from the intersection again, and into the adjacent quadrant of the intersection.
4. Then pass the needle diagonally through the intersection again from the other angle.
5. If you didn't plan well and the needle ends up in the wrong quadrant, just repeat the above process to bring the needle where you need it to continue to the next seam.

Tips on finishing the bag

When closing the final seam after inverting the ball, **do not worry about pulling the final stitches fully tight** while you are sewing. That will make the retreating stitches more difficult. Instead, finish stitching the seam closed, **loosen the last few stitches enough to stick a funnel between them** and fill the bag, and then tighten the stitches.

To tighten the stitches, use a thick tapestry needle or a similar tool to hook each stitch starting where they begin to be loose and pull it to tighten the ones behind it. As you pull on it, use your finger to press gently on the seam behind it to help the seam to close and the stitches to tighten. Do this along the whole seam until you reach the last stitch, holding the end of the thread so it doesn't pull out, and then pull the thread itself to tighten the last stitch. Then tie it off.

Tightening the stitches like this is much easier with the slick monofilament thread. Also, if you use the backstitch, **you may have trouble tightening the stitches if you pull on both threads of each stitch. Try pulling just one of them.**

If you want the **option of adjusting the amount of fill later**, don't tie off or trim the thread, and use my technique in the "Filling the Bags" section under "How to allow adjustments later".

Make sure your final thread has plenty of extra length if you intend to loosen the last several stitches to push a funnel between them, or if you want the option of reopening the bag later.

When you are ready to tie off the thread, you can **hide the end of the thread inside the bag** using the method described at the end of the "Knotting Techniques" section.

Backstitch: Basic instructions

The backstitch consists of **short retreating stitches on one side of the seam alternating with long advancing ones on the other side**. It not only produces a smooth and strong seam, but also has the advantage of locking itself against the fabric so that the stitches do not easily loosen.

1. Start with the two panels placed front to front and knot the thread (see "Knotting Techniques").
2. Begin with a short, advancing stitch (around ⅛″/3mm).
3. On the other side, make a retreating stitch back to the starting point.
4. Back on the first side, make a long, advancing stitch (twice the length of the short stitch).
5. Continue by making a short retreating stitch back to the end of the previous stitch, and then another long advancing stitch. **Thus, one side of the seam has long, overlapping, advancing stitches and the other side has short, adjacent, retreating stitches.** Each retreating stitch is half the length of the advancing stitches and should, ideally, pass through the same hole as the previous advancing stitch.

When you reach the corner of a pair of panels, A and B, and are ready to attach a third panel to A, bring the needle to A's side of the seam so you can continue around the corner and down the new A-C seam.

If the needle is already on A's side of the A-B seam, right at the corner of the pattern, make an advancing stitch down the new A-C seam and then a retreating stitch back to the corner before proceeding.

If the last stitch on the A-B seam, the one that reached the corner of the pattern, brought the needle to the wrong side of the seam, make a retreating stitch back over the last one which will bring the needle to A's side, a short distance from the corner. Then pass the needle through the corner of A and then into the corner of C (rather than through B). Then make a second advancing stitch down the new A-C seam, followed by a retreating stitch back to the corner, and then proceed from there.

For the seams that are sewn from outside the bag, I still use the backstitch but with the technique modified so it can be performed from the outside. **My technique is similar to the "ladder stitch"**. A ladder stitch is really a running stitch performed from the outside. My stitch is done the same way but **with a retreating stitch added**. If you stitch carefully and accurately and pull the stitches tight, you will get a backstitch as if it was done from the inside and the stitches will be as hidden from view as the inside stitches. **There are two approaches I have used to perform it.**

Backstitch from the exterior, Approach 1

1. Fold the seam allowance of the two adjacent panel edges into the bag along the stitching lines and pinch them together, forming two "lips" of fabric with the stitching lines along the tops, or just inside if you positioned them closer to the panel edges so as to hide them within the seam. Pin the two lips together if necessary to keep them aligned and folded along the stitching lines. Pinch the two lips together with your fingers just ahead of where you're stitching.
2. Make a long, advancing stitch in and out one lip of fabric through the "tunnel" made by the folded seam allowance (following the exposed stitching line, but preferably inside it so that the line will be hidden within the seam).
3. Then cross straight over to the other lip and make a short, retreating stitch in and out.
4. Cross over again to the first side and make another long advancing stitch.

If you wish, you can pull the stitches tight periodically which will pull the two lips of fabric more tightly together and hide the stitches between them. But you can also tighten the stitches after you're finished.

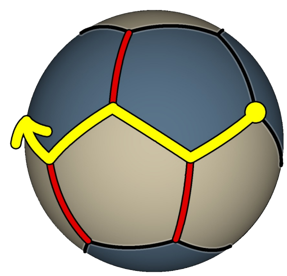
Backstitch from the exterior, Approach 2 (my new preferred method)

With a steeply curved seam or a very narrow allowance, I have found that folding the seam allowances into two lips as in Approach 1 can be very difficult. So I instead partially fill the bag to prevent it from collapsing while I work on it, and use the filler to hold the seam allowances where I want them and provide a firm base to help me push the needle through the fabric.

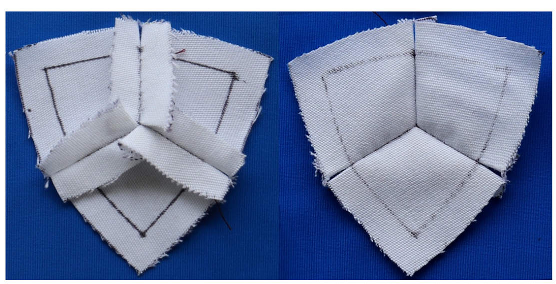
For this approach the allowances only need to be folded into the bag at the point you're stitching. Follow the same procedure as in Approach 1, but instead of a "tunnel" of fabric (formed by the folded seam allowance), there is simply a partly exposed allowance with the stitching line marked on it. Stitch in and out of each side (long, advancing stitches on one side and short, retreating stitches on the other), and every stitch or two, fold a little more of the allowance into the bag and tighten the stitches a bit.

Crossing seam intersections while sewing patches of multiple panels together

Most of my assembly methods involve first forming patches or hemispheres of multiple panels, and then sewing those patches together. As you join them, you will **encounter previously sewn seams that are perpendicular** to the seam you are sewing, and their seam allowances will be in the way.



In the dodecahedron ball illustration on the right, **the yellow line is the stitching path** to attach the two hemispheres and **the red seams are the ones that have already been sewn and must be crossed**. These are 3-way intersections, which most of my designs have. When you cross a 3-way intersection, you can use the technique below to cross through the seam allowance of the perpendicular seam, or you can bring the thread to the other side (which may require a duplicate, retreating stitch over the last one) as I described in the Basic Instructions and then simply stitch around the panel corner opposite the perpendicular seam.



My 24-panel design assembly method calls for making eight 3-panel patches like the ones shown on the right and then sewing them together. The beanbag photo shows how two of these triangular patches form 4-way intersections in the middles of their joined edges. For these intersections, you will need to cross through the seam allowances.

If you loop the thread over the top of the seam allowances, the thread will bunch it up and likely make the seam look messy. If you stitch across the faces of the seam allowances, sewing them flat against the panels, they will hide part of the stitching pattern (as they do in the left-most photo above because I ironed them down). Also, you would not be able to make a stitch right at the corner of the pattern because it would be at the very edge of the folded panel. There would be no seam allowance beyond it to prevent it from popping through the fabric.

So here is how I do it:

1. First, in the case of the 24-panel design, if you already ironed the seam allowances as shown in the photo, lift them up and work under them.

2. Make a stitch that reaches the corner of the pattern, then make a short retreating stitch.
3. Then, for the next advancing stitch, pass the needle straight through the two panels forming the perpendicular seam, right at the corner of the pattern, then down through the two patches on the other side of the intersection a short distance from the corner. (Or, you can pass the stitch diagonally through the intersection, ending up on the bottom of the seam on the other side instead of the top.)
4. Then make a retreating stitch again that retreats to just that side of the intersection and proceed from there.

The stitches that pass through the intersection (either through the two patches/hemispheres or through a pair of panels of a single patch) **should always pass through at the corners of the stitching patterns – not through the allowances outside the pattern.**

The retreating stitches at each corner form complete loops of thread through the fabric that cinch the fabric tightly together on both sides of the intersection so that the vertex will be tightly closed on the finished bag. If your vertices still aren't closed as tightly as you want, use my second method in the "Closing seam intersections tightly" topic earlier in this section to close them up perfectly. The method I just described is the first method.

Knotting Techniques

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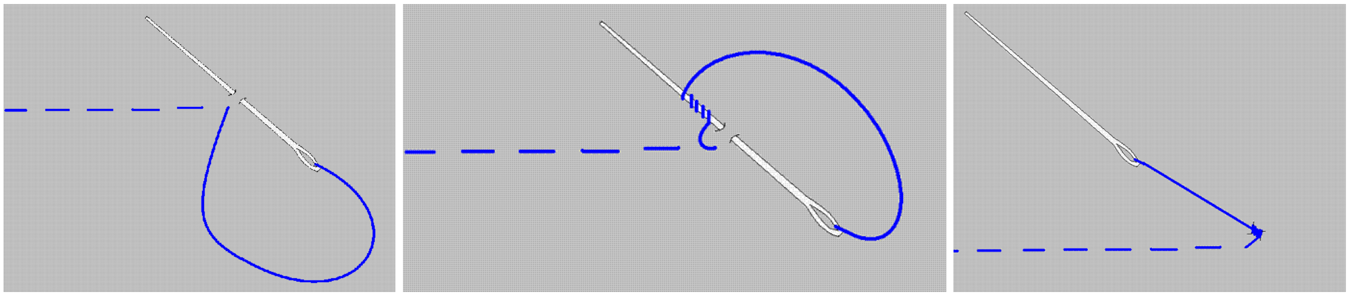
Surgeon's knot photo from
https://en.wikipedia.org/wiki/Surgeon's_knot

Tying the thread securely and tightly is important so that your stitches do not loosen and peek out or, worse, unravel. **(For whatever knot you use, to hold it more securely,** one stitcher advised me to **put super glue on the knot.)** Some people advise starting a thread by tying a large ball knot in the end of it which prevents it from pulling through the fabric. I don't trust the knot never to pop through when the beanbag is treated roughly, so I tie a **surgeon's knot** (left) around a small amount of fabric, or around the thread of a previous stitch if one is available.

To tie a surgeon's knot, **start with a double overhand knot** (the knot you use to begin tying your shoelaces, but with one additional pass) **followed by a standard overhand knot**. I usually tie the thread a stitch or two back into my previous stitching (if there is any) or make an overlapping stitch in place over the knot to make sure there isn't a loose point in the stitching.

You can also double the thread, which not only makes it stronger, but also makes knotting it very quick and easy. Put both ends through the needle's eye, run the needle through the fabric one way and back the other so both ends are on the same side, and then pass the needle through the loop made by the folded thread and pull it tight: instant knot!

I discovered a **very good method of ending the thread**. Below are illustrations for it. Stick the needle through a small amount of fabric and then back out on the same side, or under your last stitch, and leave it there, halfway through. Take the thread opposite the needle where it comes out of the fabric and wrap it around the tip of the needle three times or so. Finish pushing the needle through so that it pulls the thread through the coil you made and pull it tight. I do this a couple of times to make sure I have a secure knot, but that probably isn't necessary.



Ending knot illustration from *How to Sew by Hand* at http://www.shushanna.com/handsew.html

To hide the final knot and thread end when you close the last seam from the outside the ball, tie the knot as far into the seam as you can get it, and after you tie it, stick the needle down into the bag beside the knot and out through a nearby part of the bag so that you pull an inch or so of thread into the bag. Then squeeze the bag and trim the thread where it comes out of the bag. When you decompress the bag and kneed it a bit, **the end of the thread will be pulled back into the bag and be hidden**.

Better Seams by Ironing

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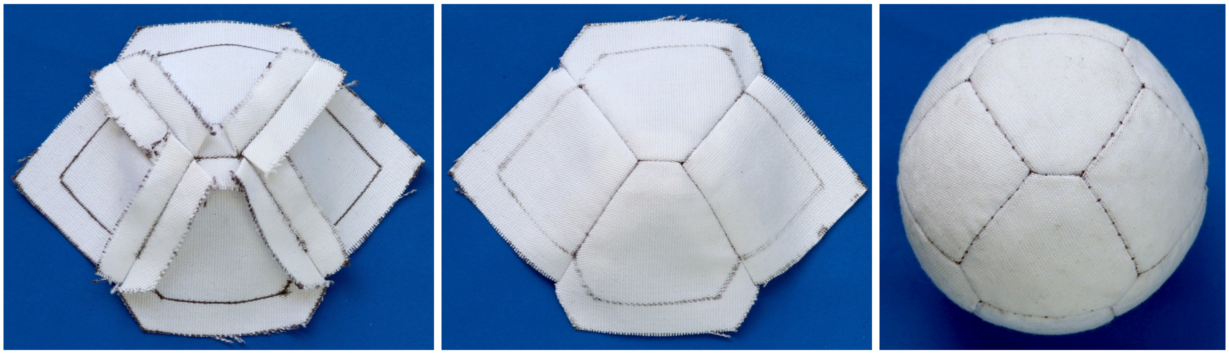
Summary

This is a technique I invented to make the finished seams look more elegant by **pressing the seam allowances flat.** The motivation behind this is that the curvature of the seams causes the seam allowances to pucker and bend in different directions resulting in lumps and ripples in the seams. Pressing them so they sit flat against their respective panels will result in **flat, straight, professional-looking seams**, and a very smooth surface on the beanbag.

Ironing my seams so that they are almost perfectly smooth like this, along with using very precise stitching, is what allows me compare the results of tiny alterations in my panel shapes. **I iron only the structures up to 14 panels** (which are the only ones with curved panel edges). The 24-panel structure is fairly easy to iron, but above 14 panels the seams are short and straight and ironing is not as important (and it is very tedious to do).



How I fold the seam allowances of the 14-panel design for ironing, and the resulting smooth seams. (I assembled this four-panel patch and ironed it just to depict the folded seam allowances. I do not normally iron this design until after the bag is assembled.)

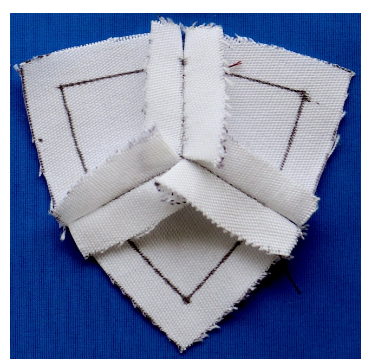
My corduroy octahedron and my corduroy and denim 14-panel beanbags, to show the effectiveness of this technique with thick fabrics.

Note that **this technique does not apply to gathered or highly rippled seams**. Also, I use 8mm (~$\frac{5}{16}$″) seam allowances when I intend to iron the allowances. The wider width is also beneficial with materials that fray a lot. **If you use a narrow allowance, you may not be able to use this technique because there isn't enough fabric to fold back and iron.** But depending on the thickness and stiffness of the fabric, it may not be important to iron the seams, anyway. Denim (which I used before I switched to corduroy) is so thick and stiff that the seams can be very lumpy when they are not flattened.

For even more smoothness and roundness, **iron the ball again after you have finished and filled it**. This is especially helpful for low panel-count designs as it also reshapes the panels and results in a better sphere. This would also help in cases when ironing the seam allowances is impractical due to the thinness of the fabric, narrowness of the allowances, or when a design's many seams would be too difficult or time-consuming to iron.

Technique for ironing the seam allowances

Before turning the bag right side out (in some cases this can be done after), **insert a finger or two into the bag** to use to press the seams against the iron. With the help of your other hand, **separate the two layers of seam allowance fabric at each seam and fold each side out flat**. **Iron them so they stay that way**. Start at the middles of the seams and work toward the intersections. When all the seams of an intersection are ironed, iron the intersection itself. First fold each panel corner down over an adjacent allowance as shown on the right, and when they are all folded, **press the entire intersection against the iron** and roll your finger around to get the entire formation flattened.



Ironed seam allowances of a group of three kite panels from my 24-panel design (I no longer iron that design, though).

I fold the corners of the allowances over each other in a pinwheel manner as shown in the photo. This is fairly quick and easy to do, at least for 3-way intersections, and makes a great-looking vertex on the bag. Just hold an allowance down and fold the adjacent one over it like a flap of gift wrap. Then proceed to each subsequent pair, holding the previous ones in place with your thumb. The tetrahedron, cube, dodecahedron, and other structures with 3-way vertices can also be folded this way.

For 4-way intersections you can either use the pinwheel formation, or fold one pair of adjacent corners over themselves down along the seam between them, and the opposing pair down their seam. The pinwheel formation produces somewhat flatter seams, though.

It may help to dampen the seams first, though be aware that the water will transfer the heat to your finger more quickly. I have not needed to dampen the fabrics I work with.

The thick fabrics I use protect my fingers from easily getting burned. Even the fabric in the photo, which is my design testing fabric and is pretty thin, is mostly safe to iron this way. I get singed a bit sometimes, but if I'm careful, I can flatten the seams without significant discomfort. Try lowering the heat setting if your finger is too easily getting burned. **If you use a very thin fabric you may not be able to use this technique**, but it is also less important for a thin fabric because the puckering won't cause as much distortion in the seams. You could instead iron the bag after filling it **to improve its smoothness**.

Readjusting the seam allowances after inverting the bag/Alternate methods

You will have to readjust the seams when you turn the bag right side out and **make sure they are still folded out flat**. You can do this with the low panel-count designs by sticking your finger inside the bag and feeling for the seam allowances and adjusting them. But there is another way that is easier for higher panel-count designs, and this can even work to some extent as a replacement for the iron method, though it won't produce as good a result.

Fill and finish the bag, and then stick a thick, blunt-tipped needle such as a tapestry needle into the bag between the panels and between the stitching and pivot it back and forth to press the allowances against the panels. I do this wherever I see bad puckering. You can also stick the needle into each vertex and press the corners of the allowances against the panels to get a very neat-looking intersection. If you wish, you can then press the entire ball against the iron along each seam so that the filler presses the seams flat and smooth.

You could also try a water-soluble glue instead of the iron, but you would have to wash the bag when you finish it to remove the glue, unless it is flexible enough not to spoil the feel of the bag. Depending on the fabric, it may also work just to dampen the seams, flatten them out with your fingers, and then let them dry that way, or fill the bag right away and let the filler hold them flat.

Another technique I read of, but have not used, is to use large running stitches (basting stitches) on both sides of each seam to keep the seams folded out flat, and then pull the stitches back out after the bag is finished. This seems overly tedious and time-consuming to me, though.

Filling the Bags (and Removing Filler)

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Filling technique

I use a **funnel** to fill the bags (with pellets or seeds). After I have filled the bag loosely, I knead it a bit to stretch out the fabric and fill in the corners. I then pack more filler in until it is tightly filled using the following method: I stick my finger down into the full funnel and stop up the spout, and then press the funnel down into the bag to stretch it out. Then I remove my finger and slowly raise the funnel while tapping it or prodding the pellets through the spout with my finger so they fill in the void left behind by the funnel's spout. I repeat this until I have a firm, spherical bag (I don't stretch the fabric to its utter limit, but just enough to make the bag firm).

Filling the bags tightly will usually improve their roundness. They will not remain quite as firm forever, but will stretch out and become softer over time (depending on your fabric choice and how tightly you stretch it).

A funnel can be used to fill a ball with fiber-fill, as well. Just use the back end of a pen or pencil or some similar tool to cram the stuffing through the funnel's spout into the ball. I used this method for the top portion of my Turtle Ball.

You can sew the opening entirely closed before fully filling the bag. All you have to do is leave the last several stitches loose (or loosen them later) and when you're finished, pull them out part way so that you can push the funnel in between them, or at least push some filler in with your finger. After filling the bag, you can pull the stitches tight again.

I retighten the stitches by sticking the tip of my automatic pencil or a thick tapestry needle under each stitch in turn starting where the stitches begin to be loose and pulling on it to tighten the stitches behind it (as you pull on it, use your other finger to press gently on the seam behind it to help the seam to close and the stitches to tighten). I continue this until I reach the end and then pull the thread itself to tighten the last couple of stitches.

You may want to use a scale to ensure that each bag is filled with the same weight of pellets. This depends on whether a **consistent weight or a consistent firmness** is more important to you (with enough accuracy of sewing and consistency of fabric choice across bags, you should be able to get both). **If you use a mix of two types of filler such as plastic and metal, a scale is more important.**

How to allow adjustments later

If you are unsure how heavy or firm you like your beanbags or how much they will soften over time, you can allow adjustments by not tying the thread at the end but instead making several whip stitches back along the last seam to keep the final seam tight, and then running the needle straight through part of the bag and pulling it out the other side and then trimming the thread, leaving the end inside the bag.

I make at least a few passes back and forth through the bag so I have several inches of thread inside before trimming it. Each pass through the bag should be far enough from the previous one that the stitch it leaves across the face of the ball is long enough that you can find it and pull it out later.

This technique gives the bag a finished look and allows you to use it for a while with the whip stitches preventing the final seam from loosening and opening. The excess thread will be available out of sight so you can retrieve it, undo the whip stitches and open the bag, and then tie the thread when you have made your final decision on firmness and weight.

Leaving yourself several inches of thread with extra passes through the bag will enable you to loosen the last few stitches holding the seam closed without actually pulling them out so that you can push a funnel or a few pinches of filler between them, and then pull them tight again.

Removing filler

To remove pellet or seed filler, loosen several stitches enough that the seam can be pulled open, stick a slender instrument like a pencil tip or thick needle into the bag, and swirl it around upside down which will simultaneously widen the opening and jostle the pellets out. To remove large quantities of filler, loosen the stitches enough to insert a funnel spout between the stitches into the bag. Then flip it and the bag upside down, and thrust the funnel in and out while kneading the bag.

To remove fiber fill, I suggest trying a small hook (a wire with the end bent over might work) to pull out tufts of filler.

Ironing the Finished Beanbag for a Better Sphere

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For low panel-count bags, or any bags that have noticeably angular or lumpy seams, **pressing the filled and finished bag against a hot iron along all the seams will improve its shape and feel**. It will make the seams more smoothly rounded and it will flatten the seam allowances and sharpen their folds, reducing the seams' prominence. It even helps the panel faces conform to a spherical shape. **It effectively breaks in the bag, reshaping the fabric a little**.

My tetrahedral bag made with my stiff, non-stretch design testing fabric started out feeling very pyramidal. After ironing it, it felt nearly spherical. My cube became perfectly spherical.

Just squash the bag firmly against the iron and rotate it slowly following all the seams. Work it back and forth a bit as you do this to help the filler press out the seam allowances and lumps. **Make sure the heat setting is appropriate** for the fabric and thread you are using. My monofilament thread melts if I set the iron too high.

My beanbag photos throughout this document have *not* been ironed in this way, and so exhibit their original shapes.

Printable Beanbag Measuring Tapes

This page is 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).* ***PDF viewers and printers can both contribute to slightly inaccurately sized prints. Compare the Circumference tapes to a ruler aligned at the bottom end and scale the next print if necessary.*** *My home prints come out slightly too small and so I have to print them at 100.3%. Prints at the library come out slightly too large and I have to print them at 99.7%.*

Print and cut out these measuring tapes to measure your beanbags. (Be sure to tell the Print Dialog to print only this page so you don't print the entire document.) **If your beanbags are not the size you expected, measuring them will enable you to calculate a corrected pattern size so that future beanbags will be the intended size.**

There are both metric (millimeter) and imperial (inch) tapes, and for each type there is one for measuring the circumference and one for measuring the diameter (its units are enlarged by a factor of *pi*). Normally, to get a ball's diameter, you would measure the circumference and divide by *pi* (3.1416). **The diameter tapes effectively divide by *pi* for you.**

You can cut the tapes short for small balls. The end with the arrow must be intact, but the other end does not.

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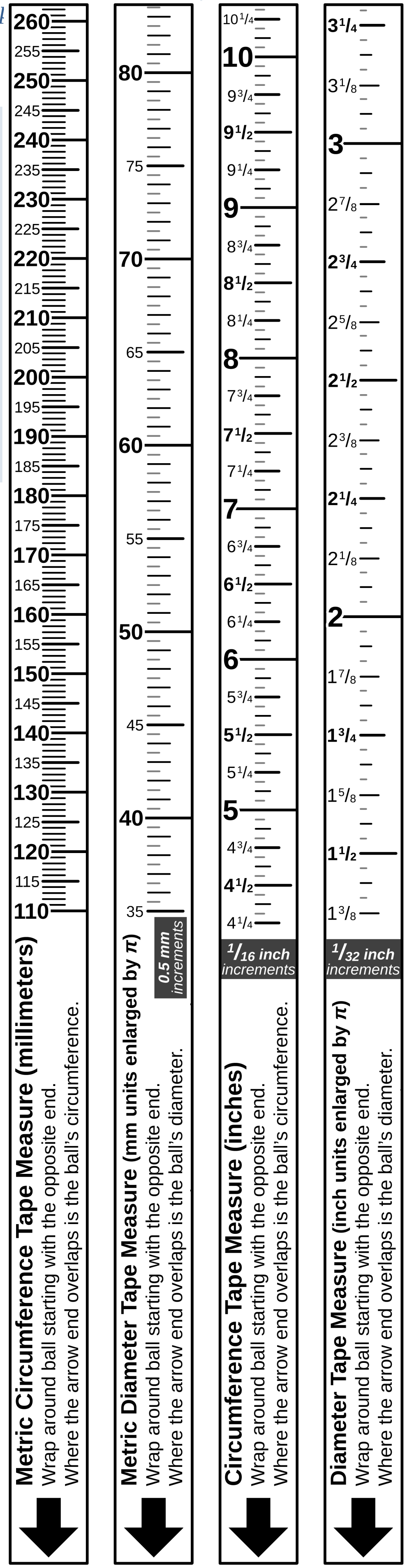


CHAPTER 3 – SKETCHUP: AN APPLICATION FOR DRAWING THE PATTERNS

I have made extensive use of the CAD (computer aided design) application called SketchUp by Trimble. I use it to draw beanbag patterns and my illustrations for this document (with the help of Photoshop). **SketchUp is a more precise way to draw and print the panel shapes than using manual tools**. While I provide ready-to-print patterns in a variety of sizes for each design, I also include both manual and SketchUp directions for drawing each pattern. I will not provide a tutorial for using SketchUp except for a few notes, but there are beginner tutorial videos and articles available on the internet.

SketchUp Make is the free version of the software, and the latest version available is 2017. **Update: Unfortunately, Trimble's website no longer offers the free version,** and the paid version is very expensive. The free version can still be found at other sources, though, such as CNET and Softsonic. **I fortunately kept the SketchUp Make installer I downloaded from Trimble. You can download it from my web server here.** There is also a free SketchUp web app, but the option to print to scale is behind a pay wall. To draw **Bézier curves** I use the BezierSpline SketchUp plugin by Fredo6.

My instructions here apply to SketchUp Make, but can be adapted to the web app, except for printing to scale.

When you launch the application, I recommend selecting the template called "**Construction Documentation – Millimeters**". My SketchUp directions use millimeter units. Make sure whatever template you use has the correct units (or remember to do the conversions: 1 inch = 25.4mm or 2.54cm).

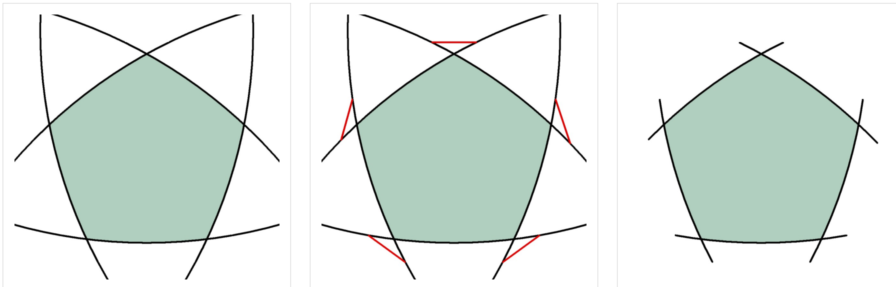
To make 1:1 printing work, and to simplify the interface for 2D drawing, set the camera to a standard view other than "Iso" such as "Top" (**Camera menu ► Standard Views ► Top**), which the Construction Documentation template will do for you, and set the camera view mode to Parallel Projection (**Camera menu ► Parallel Projection**). You can also hide the axes to clean up the interface further (**View menu ►** uncheck **Axes**).

To eliminate the fill color of polygons, go to **View menu ► Face Style** and select **Wireframe**. Or, you can erase the fill color selectively.

Circles default to 24 sides (they are actually polygons). I **set them to a high number like 90 or 180** for extra curve precision. To do this, select the Circle tool from the drop-down beside the Shapes tool (notice that a text box labeled "Sides" appears at the bottom-right corner of the window), type the number of sides you want (no need to click the text box – the value you type will appear there) and press Enter. All future circles during that session will have the new number of sides. (For very small circles, SketchUp will sometimes not allow you to use your selected number of sides, but will default back to 24. in that case, try a lower number. I have never had a problem with 90.) Incidentally, you do the same to set the number of sides for the polygon tool, though you can use the circle tool as a polygon tool. They are the same thing as far as I can tell except for their default number of sides.

Before printing, I recommend that to conserve ink and speed up printing you **erase any polygon fill color** you don't need (if you are using a Face Style that has fill color) and any extraneous lines from your design. Whatever you crop outside the view pane won't print anyway, so you don't have to delete all of the extra lines. You can erase line segments by clicking on them with the eraser tool, or by drawing a box around them with the Select (arrow) tool and pressing Delete on the keyboard. You can erase background color by right-clicking on it with the Eraser tool or the Select tool and selecting Erase from the context menu.

For arcs, especially the very shallow ones for the high panel count designs, I find it helpful to **leave some excess arc** beyond the pattern borders to help guide the scissors as they enter and leave the curve so I get a more accurately curved cut. To do this, draw a line through the arcs a short distance away from the intersections as shown below, separating the arcs into segments that can be erased separately. Then erase the portion of the circles beyond the lines, and then the lines themselves.



How to retain excess arc at each edge of circular patterns to help guide the scissors.

Back while working on the first edition of this guide I found a forum that explained how to print my patterns at a precise 1:1 scale. Here are the instructions, rewritten by me.

How to print at a 1:1 scale (applies to SketchUp Make)

1. Set the Camera view mode to **Parallel Projection** and the standard view to something other than “Iso” if you haven’t already.
2. **Zoom in on the relevant portion of the design** so that it fills the view pane as well as possible and is not cropped (the print will include everything in the view pane, including empty space, and nothing outside it). This step does not affect printing accuracy, but it prevents the empty space, and your design, from being split across multiple pages. With some trial and error you can find the optimal zoom and figure placement that will result in the pattern fitting at the edge of the page with no extraneous pages printed. It will help to resize the application window to approximately the proportions of a sheet of paper.
3. Go to **File menu ► Print Preview**, and in the Print Preview dialog:
    a) Uncheck “Fit to page”.
    b) Uncheck “Use model extents”.
    c) Under the “Scale” heading, enter the same value (e.g. “1”) and unit type for “In the printout” and “In SketchUp” to set a 1:1 scale between the application and the printout.
    d) Look at the print preview screen to see if your figure is positioned on the page as you want it to be. If it isn’t, go back and re-zoom and re-position your figure. If it is, it’s ready to print.
    e) OPTIONAL: The Print Quality drop-down changes the line quality. “High Definition” and “Ultrahigh Definition” make the lines thinner and less pixelated and therefore more accurate, but, in my experience, also make them faint and patchy. I recommend checking the “**Use high accuracy HLR**” box under the dropdown (which disables the dropdown). This will produce very fine detail, and very bold lines.

CHAPTER 4 – OTHER JUGGLING BAG AND FOOTBAG DESIGNS

A Lineup of Footbag Panel Structures

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There is a huge variety of paneled footbag designs, and most of them have higher panel counts than juggling bags, which usually have only up to 14 panels. Those who use footbags evidently see a benefit to having more panels. The most popular structure, at least for homemade footbags, appears to be the 32-panel on which I have written an instructional chapter.

Following is a lineup of panel structures that I have found, ordered by their panel counts. There are designs not represented here – the traditional juggling bag designs and some others. I included the designs that were unique to footbags, and that I liked the look of. (I created much of this list in 2013, so some of the source links no longer work. For those that are no longer available, try entering the URL into the Internet Archive Wayback Machine at http://web.archive.org/ and look for an archived version.)

1 Panel

This design from Footbag Shop is composed of a single long, slender panel with circular ends that is sewn to itself in a spiral manner.

Photo from http://www.footbagshop.com/footbags/whirlpool-single-panel.html

2 Panels

The original Hacky Sack design. This is roughly the same as the baseball structure. I have an instructional chapter about this design.

Photo from http://www.ebay.com/itm/221263945612?_trksid=p2048036

Another 2-panel design, this one using star-shaped panels. I found this at Footbag Shop.

Photo from http://www.footbagshop.com/footbags/nova-2.html

6 Panels

Photo from http://www.ebay.com/itm/6-Panels-sand-footbag-hacky-sack-item-6004-/181924436901?pt=Outdoor_Toys_Structures_US&hash=item2a2fe92ca5

I found this on eBay. Bomb Footbags also makes bags of this design, but their photos aren't as good. I actually designed a pattern that looks just like this while trying to invent a simpler version of the Volley Bag (see the section called "Volleyball style" farther on in this chapter).

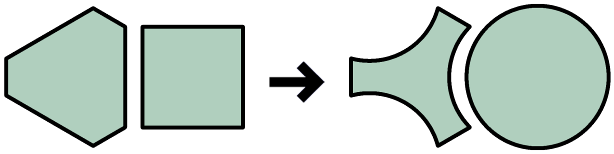
This design is conceptually similar to a dodecahedron, but with pairs of pentagons merged into single panels, and their angles transformed into curves. That is how I designed mine. I got the curves wrong, though, and their lengths didn't match, so I never made a bag of that design. As I discuss in the section on the Volley Bag, this design could also be formed by altering the square panels of the cube.

14 Panels

Photos sources:
http://www.ebay.com/itm/Nut-Sack-14-panel-Sand-filled-hackysack-kickbag-footbag-/400084852917#vi-content

http://www.footbagshop.com/reaper-14-net-red-white.html

This is a variation of the traditional 14-panel structure in which the squares have become circles and the hexagons have concave circular edges in place of the three long edges. I like its resemblance to a ladybug.



The first photo is from eBay and the second is from Footbag Shop. I designed my own version of this. It is described in the 14-panel Equidistant Cuboctahedron chapter document.

Photos from http://bombfootbags.com/TheRocket.html

"The Rocket" 14-panel footbag by Bomb Footbags.

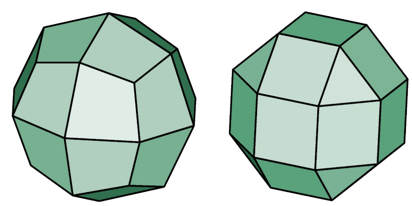
20 Panels

"Elemental" footbag from Footbag Central and three bags by Allan Petersen of Hane Dane Craft. This panel structure is the fifth Platonic Solid, the Icosahedron, composed of equilateral triangles. This is the shape used for 20-sided dice.

Elemental photo from http://www.footbagcentral.com/proddetail.php?prod=Elemental-Flow-Footbag-Hackysack
Hane Dane Craft photos from https://www.facebook.com/profile.php?id=100054375258284

24 Panels

I have written an instructional chapter on this design. My research turned up the interesting fact that this solid is called a Deltoidal Icositetrahedron and is the dual of the Rhombicuboctahedron used for the second 26-panel footbag design (on the next page). Both solids are shown on the right. Where the rhombicuboctahedron has a face, this has a vertex aligned with its center. The three-way vertices correspond to the rhombi's triangular faces and the four-way vertices correspond to its square faces.



The **Deltoidal Icositetrahedron** on the left and the **Rhombicuboctahedron** on the right are duals of each other.

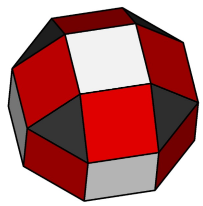
The shape of this polyhedron's faces is called a kite. According to Wikipedia, "Kite quadrilaterals are named for the wind-blown, flying kites, which often have this shape and which are in turn named for a bird."

Photo sources:
http://www.expo-star.com/lview.asp?mainid=12&Subid=0&pid=52
http://www.jugglingstore.com/pyramid-footbag-765.html
http://www.oddballs.co.uk/oddballs-sand-filled-footbags-24-panel-p-2933.html

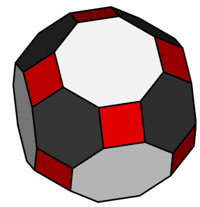
26 Panels

Photo sources:
http://www.flyingclipper.com/home/fly/page_272_99/alpha_footbag.html
http://www.flyingclipper.com/home/fly/page_461_171/dirtbag_26_footbag.html

“Alpha” and “Dirtbag” footbags by Flying Clipper. Through research on the 24-panel structure I discovered that the 26-panel structure is similar to (and is probably based on) the Rhombicuboctahedron, which is an Archimedean Solid composed of squares and triangles. This bag uses truncated triangles, though, and so it is actually composed of squares, semiregular hexagons, and semiregular octagons.



Rhombi-cuboctahedron



Truncated Cuboctahedron

Years later, while researching for the 26-panel chapter, I discovered the Truncated Cuboctahedron. That solid is composed of squares, hexagons, and octagons. So this design might actually be a Truncated Cuboctahedron with edge-truncated hexagons and octagons. I drew the illustrations above for my 26-panel chapter to show how this beanbag design is related to both polyhedra.

Photo sources:
https://hanedanefootbags.com/product/26-panel-multi-0071/
[I found the second design through a web search, but it is no longer available in the web store.]

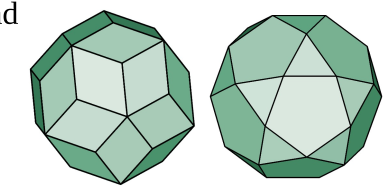
I found these 26-panel footbags while researching for my 26-panel chapter in May, 2021. These are true rhombicuboctahedra made by Allan Petersen of Hane Dane Footbags, who is the only manufacturer I have found who makes a true rhombicuboctahedral beanbag. I prefer the look of this design.

Continued on the next page

30 Panels



These are Rhombic Triacontahedra made by Allan Petersen of Hane Dane Craft. They are composed of 30 rhombi or diamond-shaped panels that meet at twenty 3-way vertices and twelve 5-way vertices. This is a Catalan solid and is the dual of the 32-face Icosidodecahedron. The two types of vertices correspond to the icosidodecahedron's twenty triangles and twelve pentagons, respectively. Interestingly, the ratio of the rhombus' long diagonal to the short is equal to the golden ratio. The first two photos inspired my instructional chapter on this panel structure.



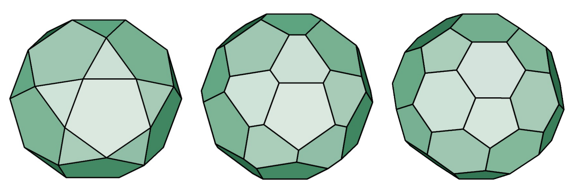
The **Rhombic Triacontahedron** on the left and the **Icosidodecahedron** on the right are duals of each other.

Photos from: https://www.facebook.com/profile.php?id=100054375258284

32 Panels




These are homemade footbags. Their panel structures can be thought of as Icosidodecahedra with truncated triangles, or Truncated Icosahedra with edge-truncated hexagons (the second photo may be a true icosidodecahedron imprecisely stitched). I show many more color arrangements in the 32-panel instructional chapter.



An **Icosidodecahedron** on the left, a **Truncated Icosahedron** on the right, and the **truncated triangle form** in the middle that is commonly used for footbags.

Photo sources:
http://modified.in/footbag/viewtopic.php?t=21008
http://modified.in/footbag/viewtopic.php?p=436817
http://modified.in/footbag/viewtopic.php?f=11&t=22702

The “Offset” – a unique 32-panel design from a series called “Footbags from a different world” published by Allan Petersen/Hanedane. This bag was made by Allan Petersen’s friend Bart. The panel structure is related to the Snub Dodecahedron with four of the Snub’s triangles combined to form each of this structure’s triangles.

Photo from https://steemit.com/footbag/@hanedane/footbags-from-a-different-world-offset

42 Panels

Photo sources:
http://www.flyingclipper.com/home/fly/page_274_99/legend_footbag.html
https://steemit.com/footbag/@hanedane/footbags-from-a-different-world-42twist

Two “Legend” footbags by Flying Clipper and the “42Twist” by Dean Anderson. These can be thought of as Dodecahedra with border panels around each pentagon. The first two are related to the Rhombicosidodecahedron (the 62-panel design) with each border panel composed of a square and a third of the triangle on each side. The third footbag is similar to the Snub Dodecahedron, if that used more and smaller triangles. Each border panel could be formed by a row of six equilateral triangles.

50 Panels

“Dirtbag” footbag by Flying Clipper. This appears to be a modified Truncated Rhombicuboctahedron.

Photos from http://www.flyingclipper.com/home/fly/page_464_171/dirtbag_50_footbag.html

52 Panels

“The Bee” footbag from Higgins Brothers. This appears to be a Truncated Icosahedron (32 panels – the soccer ball) with each of the 20 hexagons divided down the middle to form the white and gold panels.

Photo from http://www.higginsbrothers.com/html/footbags.html

62 Panels




Photo sources – top row:
http://worldfootbag.com/product/hammer-net-footbag/
http://worldfootbag.com/product/sand-hammer-hacky-sack-footbag/
http://worldfootbag.com/product/axe-hammer-footbag/
http://worldfootbag.com/product/jack-hammer-hacky-sack-footbag/

Bottom row:
https://www.facebook.com/profile.php?id=100054375258284

Top row: “Hammer Net”, “Sand Hammer”, “Axe Hammer”, and “Jack Hammer” footbags from World Footbag. Bottom row: two bags made by Allan Petersen of Hane Dane Craft. These all have the same panel structure, the Rhombicosidodecahedron, but very different color arrangements. They are composed of 20 triangles, 30 squares, and 12 pentagons.

92 Panels



Photos 1 & 2 sources:
http://www.miusports.com.pk/detail.php?nod=320
http://www.expo-star.com/lview.asp?mainid=13&Subid=0&pid=39

Photo 3 – homemade by Brian Bear:
http://modified.in/footbag/viewtopic.php?f=11&t=22702

This panel structure appears to be based on a Rectified Truncated Icosahedron, which is a soccer ball (pents and hexes) in which each vertex has been truncated into a triangle. It has 60 isosceles triangles, 12 pentagons, and 20 hexagons. These beanbags use slightly truncated triangles, though.

This is a 92-panel design from Hane Dane Craft that uses only pentagons and triangles. The panel structure is a Snub Dodecahedron. Petersen explains that this design is related to the “Offset” 32-panel design (right) in that each of the Offset’s triangles are divided into four to create this design.

Photo from
https://steemit.com/footbag/@hanedane/footbags-from-a-different-world-offset

120 Panels



Photos from http://worldfootbag.com/product/steely-120-footbag/

"Steely" footbags (filled with steel ball bearings) from World Footbag.

122 Panels

"Lotus" footbag made by Allan Petersen of Hane Dane Footbags. This is one of a collection of unique footbags displayed on his web store. It is composed of triangles, squares, diamonds, and pentagons.

Photo from https://steemit.com/footbag/@hanedane/footbags-from-a-different-world-lotus or https://hanedanefootbags.com/2020/04/18/lotus/

152 Panels


"Super Hero" footbags from Adventure Trading Inc. I like the Triforce designs in these bags.

Photo sources:
http://www.ebay.com/itm/HACKY-SACK-FOOTBAG-SUPER-HERO-152-PANEL-RED-WHT-BLUE-/170521186119
http://www.amazon.com/Super-Hero-Yellow-Blues-152-Panel/dp/B005M35IUM/ref=sr_1_1?ie=UTF8&qid=1375798596&sr=8-1&keywords=super+hero+footbag
http://www.sears.com/adventure-trading-super-hero-black-grey-white-152/p-SPM7003085208?prdNo=17

182 Panels




“BB King” footbags from World Footbag, a homemade footbag by David Leberknight, and the “Don’t Blink 182” made by Allan Petersen of Hane Dane Footbags, part of a collection of unique footbags displayed on his web store.

Photo sources:
First two: http://worldfootbag.com/product/bb-king-footbag/

Third: http://www.leberknight.com/footbags.html
Fourth: https://hanedanefootbags.com/2020/04/18/dont-blink-182/

452 Panels

Photo from https://steemit.com/footbag/@hanedane/footbags-from-a-different-world-the-fahrenheit-452
or https://hanedanefootbags.com/2020/04/18/fahrenheit-452/

“Fahrenheit 452” footbag made by Allan Petersen of Hane Dane Footbags. This is one of a collection of unique footbags displayed on his web store. It is composed of triangles, squares, pentagons, and hexagons. It took five 8-hour days to complete. Here are a couple of excerpts from the description:

> “Disclaimer: this bag isn’t the best for freestyle… when I make an intricate bag like this, it’s for love of design. Form over function when it comes to these unique footbags.”

> “Like the Don’t-Blink-182, the sewing technique involves only attaching panels at the corners. Because of this, closing the bag becomes much more difficult. I had to use four or five needles at the same time to close this bag.”

Three-Dimensional Panels

Photo from https://worldfootbag.com/product/sand-blister-footbag/

Following are designs using 3D panels, meaning that each of the primary panels of the ball's structure is itself composed of multiple panels forming a pouch that holds filler. In some cases the pouches are entirely closed, individually filled units, and either join together in the center of the ball, or the inside of the ball is hollow. In other cases the pouches are open to the interior of the ball and the entire ball is filled.

The 44-panel, icosidodecahedral "Sand Blister" on the left is sold at the World Footbag webstore and was designed by Allan Petersen of Hane Dane Craft. The rest of the footbags were designed and made by him. I found all the designs below on Petersen's Facebook page, Unique Footbags by Hane Dane Craft. Each image is linked to its own blog page.

"Shock Absorber" – a hollow ball with a shell composed of 12 filled pentagonal pouches.

"Shroom" – 12 pentagonal and 20 hexagonal pouches; 64 panels total.

"Cat's Paw"

"Tesseract"

The Tesseract is hollow inside.

"Ninja 3000" – 24-panel shell of three-point stars with inner 32-panel mini bag (truncated icosahedron/soccer ball).

Inner 32-panel ball removed

"Grid" – 20 triangular pouches, 60 panels

"Jax" – composed of 6 cylinders

"Candy Bag" – 6 cubes, 8 pyramids, 68 panels

"Red Buttons" – 74 panels

"Morning Star" – an icosidodecahedron with a pyramidal spike for each triangle.

"6-Point Star" – one open compartment inside

"12-Point Star" – one open compartment inside

"Dog Turd" – 6 panels

Volleyball Style

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Volley Bag photos from ~~http://www.jugglingstore.com/volley-bag-737.html~~ [no longer available]

This 12-panel juggling beanbag design was sold years ago at various online juggling stores, but it seems no longer to exist. I found it in 2012 and loved the look of it. It was called the “Volley Bag”. Early in the drafting of my original guide I tried and failed to figure out how to design the panel shape. I very much wanted to make a bag like this, but I did not know enough geometry to tessellate the surface of a sphere in this manner.

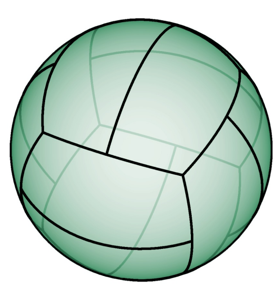
While writing the original guide I conceptualized each pair of panels as being similar to a joined pair of pentagon panels from the dodecahedron, but with the angles converted into curves and the resulting shape divided down the middle.

Years later while creating the Second Edition guide, I saw that it is similar to a cube. Each pair of panels could be formed by starting with a square and converting two of its edges into convex curves and the other two into concave curves, and then dividing the shape into two halves.

Then, while writing the 30-panel Rhombic Triacontahedron chapter, I realized that the 5-panel groupings I used for my assembly method closely resembled the shape of the pairs of panels on the Volley Bag. That seems like the best way of the three to derive the panel shape from a polyhedron.

These three designs could be used to derive the Volley Bag design.

However, now that I have created the baseball pattern and made a few bags of that design, I know from experience that sewing convex and concave curves together is difficult and tedious. So I doubt I will actually decide to design this bag.



In September, 2024 I designed my "simplified volleyball" pattern. The design is a spherical cube with each panel divided in half and the new edges rounded to form a much more spherical shape. When the panel pairs are oriented at right angles to each other, the ball is similar to the Volleybag, but is easier to assemble because all the edge curves are convex.

Elegant Leather Juggling Balls

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How to Make Leather Juggling Balls by Juggling Balls Australia

https://www.jugglingballs.com.au/how-to-make-leather-juggling-balls/

This is an online article that provides a brief, general overview of the materials, techniques, and steps involved in making leather juggling balls.

Examples of leather juggling balls made by online crafters

These leather balls by EmCouros Slow Leather Atelier are made from a single, flower-shaped panel and are baseball-stitched. This panel shape only works with edge-to-edge construction like this, because it would not allow for seam allowances at or near the lobe intersections.

Handmade leather ball photos from Emcouros Slow Leather Atelier store on Etsy: https://www.etsy.com/shop/EmCouros

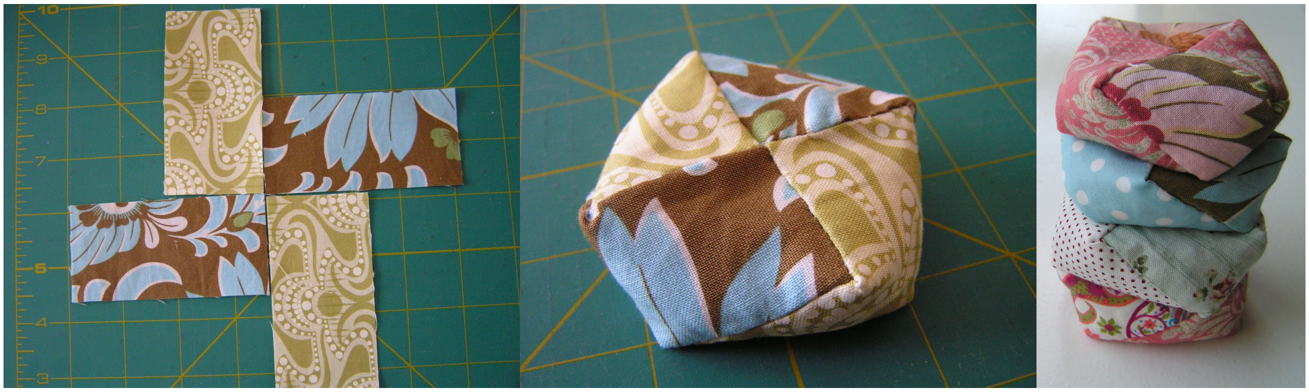
This is another ball by the same leatherworks company as the ones above (EmCouros). It uses a six-pointed flower panel. I had never before seen thread used decoratively like this. I like the elegance of this subtle, colorful effect.

Handmade leather ball photo from EmCouros Slow Leather Atelier store on Etsy: https://www.etsy.com/shop/EmCouros

This photo is from another leatherworks company on Etsy called LimburgLeer.

Handmade leather balls from LimburgLeer store on Etsy: https://www.etsy.com/listing/729773288/custom-leather-juggling-ball

Japanese Otedama Beanbags (a.k.a. Ojami)

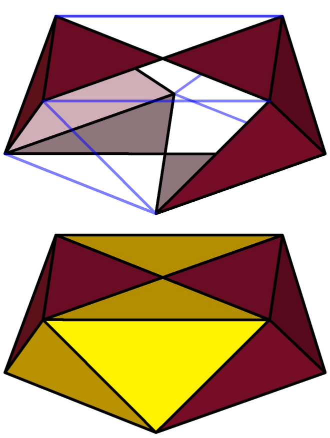


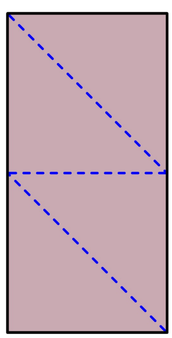
Photos from http://www.livingwithpunks.com/2011/06/sys-japanese-otedama-bags.html

I found a very interesting beanbag design in which four rectangles are sewn together in a pinwheel fashion to form a polyhedral patty, and which can be modified to form a cube. Further research identified this as the traditional design for “ojami”, the small beanbags used in the Japanese children’s game of “Otedama” (some sources say that both terms refer to the beanbags but are in different dialects).

The game is reportedly similar to Jacks or Knucklebones and the bags are made small enough for a child to be able to hold five of them in one hand. The smallest pattern I found was 2.5cm by 5.5cm (not including seam allowance), and a commenter claiming to have experience with Otedama said that this was the correct panel size[26]. This would make the middle photo above roughly life-size when this document is zoomed to 100% or printed (the width of the bag’s square faces would be 1.4″/3.5cm).

This design is angular rather than spherical and so doesn’t strictly belong in a document about spherical beanbag designs, but I like the look of it and I find the panel structure intriguing, so I included it anyway.





1:2

I think the panel proportions (the stitching pattern, not the cutting pattern) ought to be 1:2 as this ratio produces the square antiprism shown on the left in which the top and bottom square faces are rotated 45° from each other and have a ring of eight 45-45-90 triangular faces between them. This is what most of the photos of these beanbags look like, but each of the two ojami patterns I have seen uses a different rectangle and they are both longer than the 1:2 rectangle. (The tutorial from which I obtained the photos above calls for a 1¾″ × 3½″ cutting size which is 1:2, but subtracting the standard ¼″ seam allowance from each side results in a 1:2.4 ratio. This may have been an oversight by the author. The 2.5cm × 5.5cm panel size I mentioned is a 1:2.2 ratio.) The panel diagram above includes the fold lines to help you understand how it wraps around the bag.

26 “Basic Otedama: A Tutorial” – http://melyndahuskey.wordpress.com/2007/07/01/basic-otedama-a-tutorial/

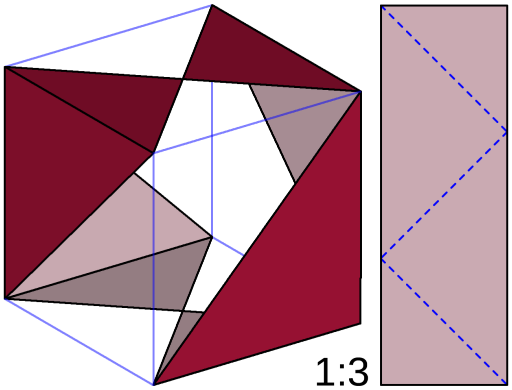


Photo from *Juggling Balls: a step by step sewing pattern* (http://juggleballs.amielmartin.com/)

The first tutorial I found for this type of design used a pattern modified to produce cubes for juggling (URL below the photo). For a cubic bag the panel is a 1:3 rectangle. The tutorial calls for 2″ × 5″ rectangles with ¼″ allowances, for a 1½″ × 4½″ (3.81cm × 11.43cm) stitching size. The diagrams above show the panel with the fold lines and how two opposing panels fit into the cube.

In both variations of the design, the short side of the panel runs one half the diagonal of the square face. This fact can be used to calculate the stitching pattern size for a desired beanbag size. A 2.5″ (6.35cm) cube, for example, would have diagonals of 8.98cm. So the short side of the panel would be 4.49cm. The long side is calculated using the appropriate ratio which in this case is 1:3, making the long side 13.47cm.

The ojami design is used by some Japanese companies for sitting cushions or throw pillows. I love this idea and the look of the cushions and so I'm presenting it here as a craft idea. Below are some examples.

http://www.jcrafts.com/eg/shop/special.asp?id=ojami

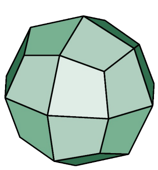
http://www.takaoka-kyoto.jp/english/products_page/iroiro_ojyami2.e.html

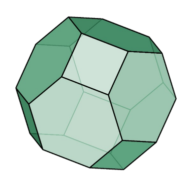
CHAPTER 5 – DESIGNING OPTIMAL SPHERES FROM POLYHEDRA – ISOVERTEX FACES, EQUIDISTANT TRANSFORMATIONS, ARCS, BÉZIER CURVES, AND THE TANGENT-CHORD ANGLE THEOREM

Chapter Index

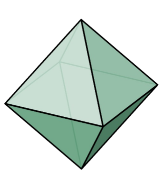
Introduction

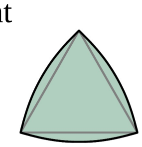
Some polyhedra, when used as they are, produce poorly-shaped cloth balls, at least judged by people like me who have a passion for designing perfect spheres. **This chapter describes techniques I have developed over the years to modify polyhedra so that they form optimal fabric spheres.**

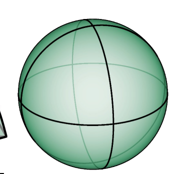




Catalan solids like the one on the left have vertices that have differing configurations of corner angles forming them and are differing distances from the center of the solid. Archimedean solids like the one on the right have faces with differing shapes/sizes and distances from the center. The balls produced by polyhedra like these will not have a uniform roundness, but will bulge outward more where there are vertices or faces that are sharper/smaller and farther from the center. This issue will not always be significant enough to matter, especially for polyhedra with a large number of faces, but some designs benefit greatly from the modifications in this chapter that eliminate these characteristics.







Straight-edged patterns work well for most high panel-count balls, and they are easy to make templates of and quick to trace and cut out, which is important with a large number of panels. However, polyhedra like the octahedron on the left with few, and therefore large, faces or with long edges and sharp vertices, will produce an angular ball since cloth will not distort enough to entirely overcome these characteristics. These designs benefit from curved panel edges. The curves eliminate the vertex pointedness, give the seams a round profile instead of angular, and allow the panel faces to bulge outward more, resulting in a good approximation of a sphere.

Choosing a Fabric for Testing Designs

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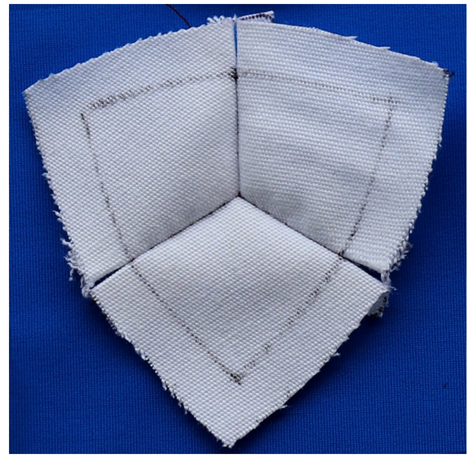
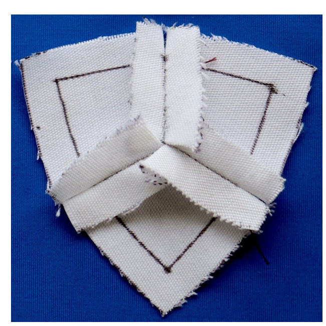

The “White Target” fabric I use to test patterns

An important aspect of designing patterns is choosing an appropriate fabric to test them with. The shape of the ball that a panel design produces is heavily influenced by the characteristics of cloth and the effects of sewing it together and inflating it with filler. Because of this, math and theory alone will not always result in a good pattern and experimental balls must be made. The fabric used for this must have the right attributes to be effective.

Woven fabrics, especially loosely woven, do not stretch uniformly and so can greatly alter the ball’s shape, especially in low panel-count designs. For example, using a lengthwise, widthwise, or diagonal grain orientation on orange peel panels can cause the ball to take on an apple shape, a barrel shape, or a lemon shape, respectively. (If you want a design like that to work for woven fabrics, you will need to choose a grain orientation and design the patterns for that orientation.) Designs like the cube and octahedron can be lopsided if the panels’ grain orientation is not balanced around the ball.

Flimsy or stretchy fabrics are too forgiving to accurately manifest the effects of the panel shapes and so provide poor design feedback. Even a poorly designed panel shape can produce a perfectly round ball if the panels can stretch, flex, and distort too easily. But it may not work well with a more robust fabric or leather. On the other hand, **a fabric that is too stiff or thick can introduce its own distortions in the ball shape, especially at the seams and corners** where the folded fabric can bulge and skew the seams.

So the best choice is a non-stretch fabric that is moderately robust and stiff, has little or no bias effect, and can both fold sharply and cleanly at the seam allowances and also mostly hold its shape when the ball is filled. For my design testing I use a moderately thick and stiff, tightly-woven, non-stretch fabric called “**White Target**” (in Jo-Ann Fabric’s sportswear section – item #16734915), though even that fabric has some bias effect. This fabric is basically a worst-case scenario. If my patterns can produce a good sphere with a fabric that can't stretch or distort much, they will only produce a better sphere when the fabric can stretch. I sometimes use a **thick and sturdy felt** for further testing. Felt, while not elastic, stretches a bit, and stretches uniformly, so it can be used to test how a pattern would respond to something mildly stretchy like a soft suede. **Marine vinyl** is a good alternative to stiff leather.



I also iron the folded seam allowances flat against the panels after assembling the balls so the allowances do not pucker and bend in different directions and produce lumps and ripples in the seams. This gives me very precise results. (I do not iron the felt balls, though, and I use a narrower allowance for those.) The sample on the right shows how I iron a 3-way panel intersection. See Chapter 2 under Better Seams by Ironing for my ironing technique.

Isovertex Faces for Better Catalan Polyhedral Balls

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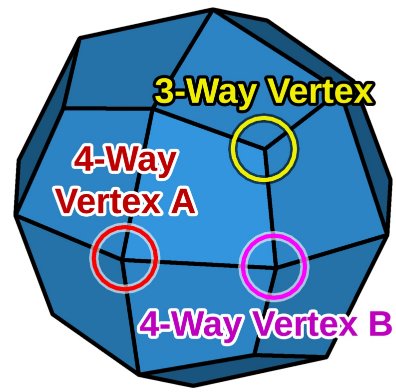
Introduction and general discussion

"Isovertex" is a term I coined for a polyhedron modification technique I invented while designing my rhombic triacontahedron pattern in 2022. It describes a polyhedron with two or more different types of vertices whose faces have been modified to produce equal sums of corner angles at all vertex types. This produces a better cloth sphere, though not a true polyhedron, because the faces no longer fit together without bending.

The Isovertex modification does not apply to Platonic and Archimedean solids because their faces have equal corner angles and their vertices are all formed by the same configuration of corners, and so the vertices already have the same shape and are the same distance from the center of the solid. Examples of Platonic and Archimedean solids are shown on the next page.

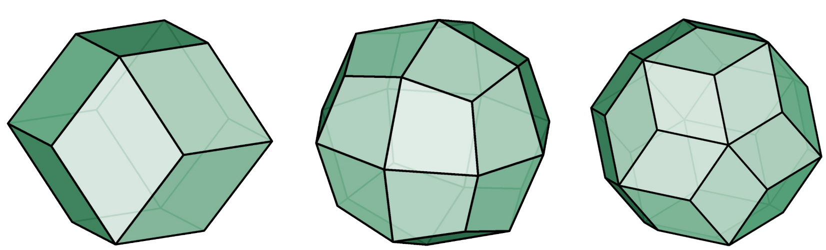


Catalan solids have faces with unequal corner angles, and thus differing types of vertices. The Deltoidal Icositetrahedron on the right is composed of kite faces, which have up to three different corner angles, and they form 3-way and two types of 4-way vertices.

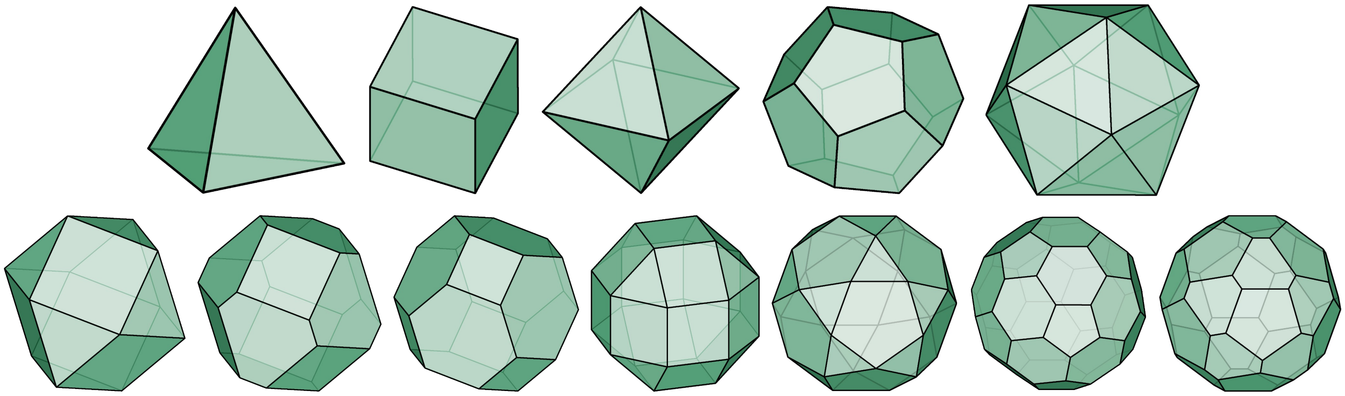
When there is enough difference between the vertices that are sharper and farther from the center and those that are blunter and closer to the center, **the resulting cloth ball will not be uniformly spherical**. The sharper vertices will bulge farther out than the others and be more angular, and **the panels will also not be stretched in a uniform manner when the ball is filled**, sometimes resulting in tension ripples as in the case of my unmodified rhombic triacontahedron ball shown farther on in this section.

The Isovertex modification can be used alone or in conjunction with curved panel edges. **With enough faces and sufficiently short edges and blunt vertices, curves are not needed** in my experience. My designs of 24 panels and higher are quite smoothly round without curves, even with stiff fabrics, while my 12-panel rhombic dodecahedron did need curves.

I used the isovertex modification for my Catalan solid-based Deltoidal Icositetrahedron (24 panels) and Rhombic Triacontahedron (30 panels). I experimented with it for the Rhombic Dodecahedron (12 panels), but while it worked fairly well, that design, as I mentioned, also needs curved edges to make a smooth ball. These three polyhedra are shown below.

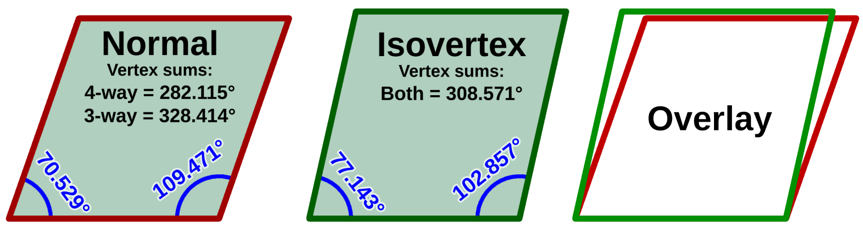


The 12-face **Rhombic Dodecahedron** (left), 24-face **Deltoidal Icositetrahedron** (middle), and 30-face **Rhombic Triacontahedron** (right) are Catalan solids and have **differing vertex types**. Some vertices are formed from acute face corners and some from obtuse corners, differing numbers of corners come together to form the vertices, and they are not at equal distances from the center.



The five **Platonic solids (top)**, and some **Archimedean solids and a couple of my designs (bottom)**. These all have **matching vertices**.

The isovertex modification, by making all the vertices equal (in terms of the sum of face angles forming them), **makes Catalan solids produce balls that are as uniformly round as balls based on Platonic solids**.



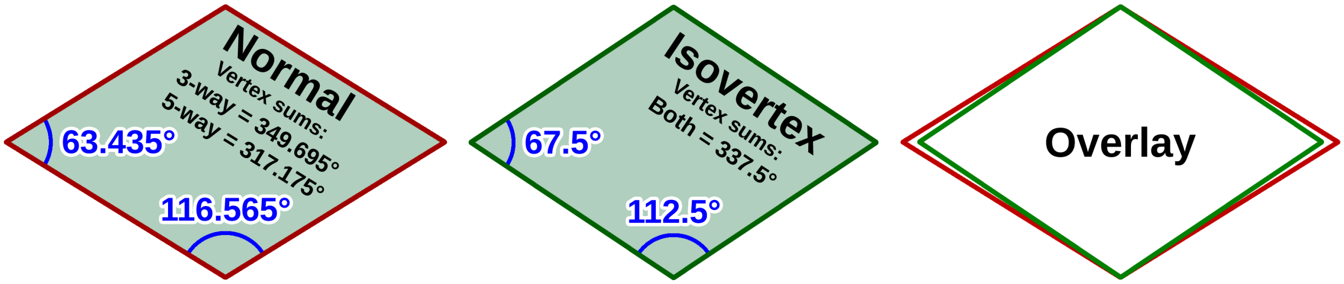
The isovertex modification worked surprisingly well without curved edges even for the **rhombic dodecahedron (12 faces)**. I made a pair of balls with my moderately stiff and non-stretch design testing fabric, one using the normal rhombus and the other using the isovertex rhombus (both without curved edges). **The normal rhombic dodecahedron made a very angular shape**, with sharp 4-way vertices that protruded far out and 3-way vertices that were pulled flat, resulting in a severe octahedron shape. **The isovertex rhombus, on the other hand, actually made a pretty good ball**. It was a little lumpy and misshapen, and not up to my standards, but was quite round and smooth enough for juggling. Most people would probably consider it a nearly perfect ball. (I do not have photos of these balls.)

Because the isovertex modification, at least in the experiments I've done, gives the face shape more nearly equal dimensions (making the rhombus more nearly a square, for instance), it would probably work better than curved edges alone (at least circularly curved) to produce a uniformly round ball with no vertices that bulge farther than others. (It might be possible to design a Bézier curve that would produce a uniform ball and uniform panel tension using the normal face shape, but I have not tried.)

The rhombic dodecahedron, for example, while it needed curves to form the best ball, also needed a modified base rhombus that was nearly the isovertex rhombus. Based on my experiments, I do not believe that circular curves alone would have been able to make the normal rhombus produce as uniform a sphere as the isovertex modification alone did.

The unmodified rhombic triacontahedron (30 faces) made a tolerably good cloth ball, but not excellent. In both the 2.5″ and 3″ ball I made (using the same fabric as the rhombic dodecahedron balls) the 5-way vertices protruded outward noticeably, and the panels had slight tension ripples running parallel to the short diagonal, as if the 5-way vertices were being pulled inward, compressing the panels from acute corner to acute corner, and the 3-way vertices were being pushed outward, putting tension on the panels in the perpendicular direction (as might be anticipated when this shape is inflated into a sphere). **I attempted to show these defects in the photos below.**

By modifying the rhombus panel shape into the isovertex shape, I was able to produce a perfectly round and balanced ball with no tension ripples on the panels and no vertex prominence at all.



Rhombus shape comparison for the **Rhombic Triacontahedron**

Left: Protruding 5-way vertices produced by the normal rhombus (top vertex displays this best – note the slight pear shape of the ball at this angle). **Middle:** Uniform roundness resulting from the isovertex modification. **Right:** Tension ripples on the normal rhombus beanbag (shown best around the foremost vertex). Most of the panels had these ripples, but they are difficult to capture with the camera. I need the right angular light to make them cast shadows.

Calculating an isovertex face's angles

I will demonstrate the isovertex calculations first for a rhombic polyhedron and then for deltoidal and pentagonal polyhedra. There are two ways to calculate the isovertex angles. I originally used the **algebraic method**, but I later discovered the **weighted average method**. I have not formally proven that the weighted average method will always have the same results, but I have tested it on six polyhedra: the Rhombic Dodecahedron, the Deltoidal and Pentagonal Icositetrahedra, the Rhombic Triacontahedron, and the Deltoidal and Pentagonal Hexecontahedra.

(Note that angles are are rounded to three places and other numerical values to six places.)

Rhombic polyhedron example

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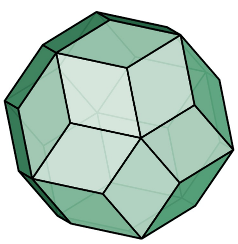
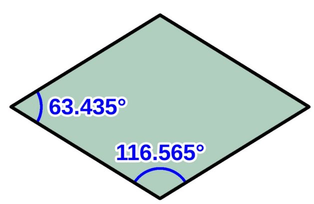


A rhombus has two different angles and produces two different vertex sums. The 30-face rhombic triacontahedron, for example, has 3 × 116.565° = **349.695°** vertices and 5 × 63.435° = **317.175°** vertices. The 5-way vertices are significantly sharper and farther from the center than the 3-ways (9.8% farther by my Sketchup measurements).



Rhombic Triacontahedron Isovertex Rhombus – Algebraic Method

I will define ***a*** **to be the acute angle** and ***b*** **to be the other angle**. I will create two equations defining the necessary properties of the angles, perform a substitution, and solve.

$\mathbf{a + b = 180°}$ (property of a rhombus)
$\mathbf{5a = 3b}$ ► $b = \frac{5}{3}a$ (definition of an isovertex rhombus forming 3-way and 5-way vertices)

Substitution into the first equation: $a + \frac{5}{3}a = 180°$

Solve: $\frac{8}{3}a = 180°$ ► $a = \frac{3(180°)}{8}$ ► **Acute angle, a = 67.5°**

So the **Obtuse angle, b** = 180° – 67.5° = **112.5°**

Rhombic Triacontahedron Isovertex Rhombus – Weighted Average Method

The two vertex sums on the normal polyhedron are

5-way vertex sum ≈ 5(63.434949°) ≈ 317.174744°
3-way vertex sum ≈ 3(116.565051°) ≈ 349.695154°

To calculate the count of each vertex type on the polyhedron, take the count of each type of corner on the face (2a and 2b), multiply each by the number of faces (60 each), and divide each by the number meeting at the corresponding vertex type (60a/5 and 60b/3). There are 12 5-ways and 20 3-ways. So

$$\textbf{Weighted average} \approx \frac{317.174744°(12)+349.695154°(20)}{32} = \mathbf{337.5°}$$

Then simply divide that by 5 to get the acute angle and by 3 to get the obtuse angle.

Acute angle = $\frac{337.5°}{5}$ = **67.5°** **Obtuse angle** = $\frac{337.5°}{3}$ = **112.5°**

Continued on the next page

Deltoidal and pentagonal polyhedra examples

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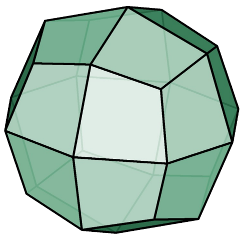
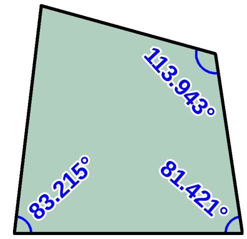


A kite has up to three different angles and so can produce up to three different vertex sums. The 24-face deltoidal icositetrahedron has a kite face whose two lateral corner angles match the angle opposite the obtuse corner (81.579°), and so produces only two different vertex sums. But the kite pattern I originally designed (shown on the right) by designing a modified deltoidal icositetrahedron (left) has three different angles.

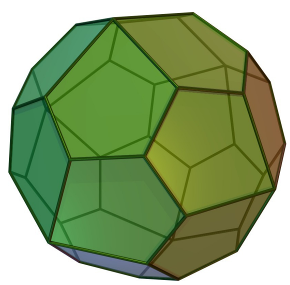
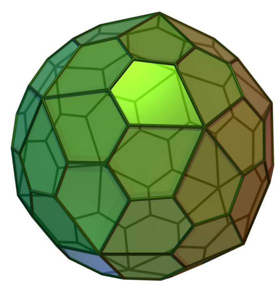


However, since the lateral corners and the corner opposite the obtuse angle both form 4-way vertices on the polyhedron, those two angles must be equal on the isovertex kite so as to produce an equal sum at both of those vertex types. This means the isovertex kite will have only two different angles, and so in the algebraic isovertex calculations only two angle variables (and, thus, two equations) are needed just as in the rhombic example above.

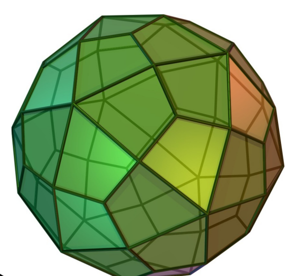
The only difference is that, since all four angles are accounted for in the first equation instead of just an acute and obtuse angle pair, their sum must be 360° instead of 180°. So the equations are:

$3a + b = 360°$ (a quadrilateral's angles must sum to 360°)
$4a = 3b$ (definition of an isovertex kite forming 3-way and 4-way vertices)

The weighted average method and counts of each vertex type on the polyhedron are also calculated as shown in the rhombic example. The Deltoidal Hexecontahedron example below shows a more complicated kite example.

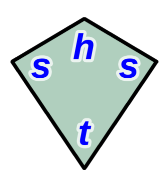
Similarly, the irregular pentagonal faces of the two pentagonal Catalan solids[27], the Pentagonal Icositetrahedron and Pentagonal Hexecontahedron, form only two different vertex multiples and angle sums. So the isovertex calculation for those shapes is as simple as with rhombic polyhedra and the deltoidal icositetrahedron. The total of the face's angles in this case is 540°. I have not worked with these polyhedra, but I calculated their isovertex face angles as a mathematical experiment.



The **60-face** **Deltoidal Hexecontahedron**[28], on the other hand, (which I have also not worked with) has 3-way, 4-way, and 5-way vertices. Calculating this isovertex shape is a bit more complicated.

To make the kite corners easier to refer to, I will use the following names and variable abbreviations:

h = obtuse, "**head**" corner (118.269°)
s = "**shoulder**" corners: the two matching side corners (86.974°)
t = "**tail**" corner, opposite the head (67.783°)



27 Pentagonal Icositetrahedron and Pentagonal Hexecontahedron (cropped) illustrations from Wikipedia, licensed under CC BY-SA 3.0 at https://commons.wikimedia.org/wiki/File:Deltoidalhexecontahedron.jpg

28 Deltoidal hexacontahedron kite angles and vertex distributions obtained from Wikipedia. Illustration from the same page, licensed under CC BY-SA 3.0 at https://commons.wikimedia.org/wiki/File:Deltoidalhexecontahedron.jpg

Following is how I would solve for the Deltoidal Hexecontahedron's isovertex kite.

Deltoidal Hexecontahedron Isovertex Kite – Algebraic Method

My starting equations are:

$h + 2s + t = 360°$ (a quadrilateral's angles must sum to 360°)
$3h = 4s = 5t$ (definition of an isovertex kite forming 3-way, 4-way, and 5-way vertices)

I would first solve the second, compound equation for s and t in terms of h ($s = \frac{3}{4}h$ and $t = \frac{3}{5}h$) and substitute the results into the first to allow me to solve it for h:
$h + 2(\frac{3}{4}h) + \frac{3}{5}h = 360°$ ► $\frac{62}{20}h = 360°$ ► **$h = 116.129032°$**

Then similar substitutions to solve for s:
$\frac{4}{3}s + 2s + \frac{4}{5}s = 360°$ ► $\frac{62}{15}s = 360°$ ► **$s = 87.096774°$**

And then substitute both of those result values into the first equation to solve for t:
$116.129032° + 2(87.096774°) + t = 360°$ ► $t = 360° – 116.129032° – 174.193548°$ ►
$t = 69.677419°$

Deltoidal Hexecontahedron Isovertex Kite – Weighted Average Method

The three vertex sums on the normal polyhedron are

3-way vertex sum ($3h$) ≈ 3(118.268677°) ≈ 354.806032°
4-way vertex sum ($4s$) ≈ 4(86.974155°) ≈ 347.896622°
5-way vertex sum ($5t$) ≈ 5(67.783012°) ≈ 338.915058°

To calculate the count of each vertex type on the polyhedron, take the count of each type of corner on the face ($1h$, $2s$, $1t$), multiply each by the number of faces ($60h$, $120s$, $60t$), and divide each by the number meeting at each corresponding vertex type ($60h/3$, $120s/4$, $60t/5$). There are 20 3-way, 30 4-way, and 12 5-way vertices on the polyhedron. So

$$\textbf{Weighted average} \approx \frac{354.806032°(20)+347.896622°(30)+338.915058°(12)}{62} \approx \textbf{348.387097°}$$

Then simply divide that by each vertex's corner multiple to get the kite angles.

$$\textbf{3-way angle, } h \approx \frac{348.387097°}{3} \approx \textbf{116.129032°}$$

$$\textbf{4-way angle, } s \approx \frac{348.387097°}{4} \approx \textbf{87.096774°}$$

$$\textbf{5-way angle, } t \approx \frac{348.387097°}{5} \approx \textbf{69.677419°}$$

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Equidistant Transformation for Uniform Archimedean Polyhedra

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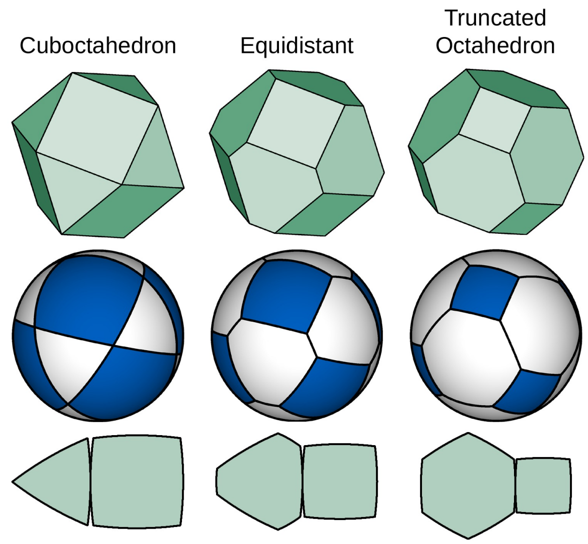
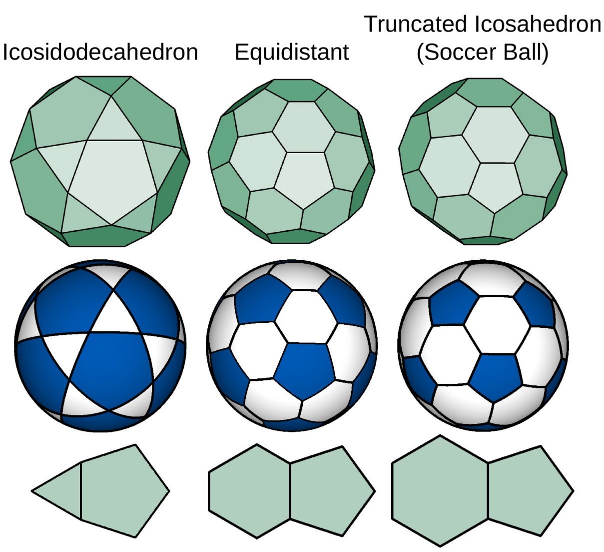
This is is a polyhedron modification technique I invented in 2013. I will introduce it and give a brief explanation of the method, but I do not at present know how I could fully explain it in a generalized manner. However, I used this modification for two beanbag designs and I wrote detailed and illustrated explanations of the process for each. I will provide links to those discussions.

This technique applies to polyhedra having two or more different face shapes, of which one (or more) is significantly larger or smaller than the other(s). (I have only done this for solids with two different face shapes.) A face that is smaller, which also means it is farther from the center, will bulge out farther than the other on the finished ball. The differing face sizes will also prevent certain kinds of color arrangements from working well (example on the next page).

The "Equidistant" transformation places both faces at the same distance from the center of the solid, and (at least in my two designs) gives the two faces a much more nearly equal size. This is accomplished by truncating either the corners or the edges of one of the face shapes and changing the size of the other. The resulting polyhedron is better suited to forming a good ball, though it may still need curved panel edges to be smoothly round if it has long edges and sharp vertices.

I did this first for the Cuboctahedron in 2013, converting it into the Equidistant Cuboctahedron. (My original reason was actually to reduce the prominence of the vertices to produce a better 14-panel ball, because I did not at that time know how to design curved panel edges.) The illustration on the right shows how both the Cuboctahedron and the Truncated Octahedron can be transformed into the Equidistant form in the middle by either corner-truncating the triangle faces or edge-truncating the hexagons, which changes the size of the squares. This changes the relative distance from the solid's center of the two face shapes. The result is a more uniform shape, and, in my opinion, an improved appearance.



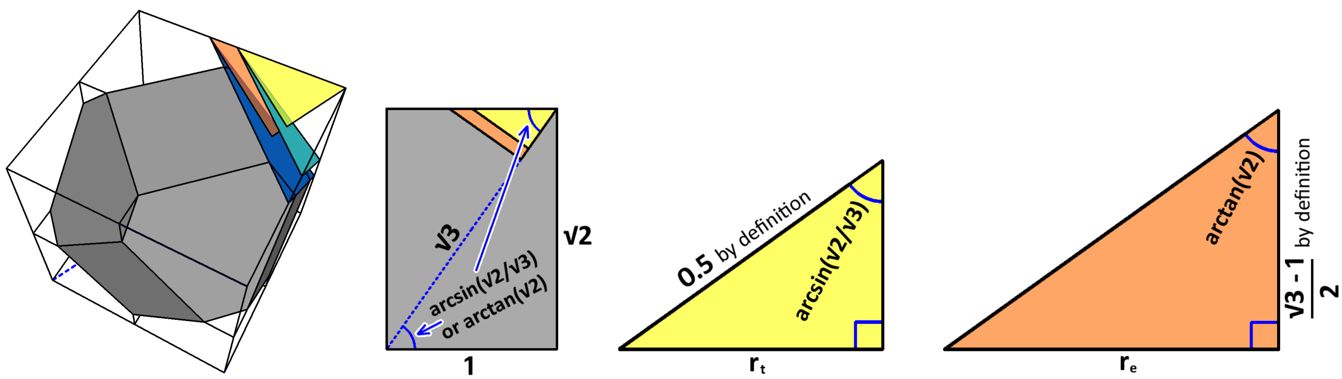


I used a fairly complicated mathematical process to design my Equidistant Cuboctahedron. I described and illustrated it in the "How I Developed This Design" section of the Equidistant Cuboctahedron chapter.

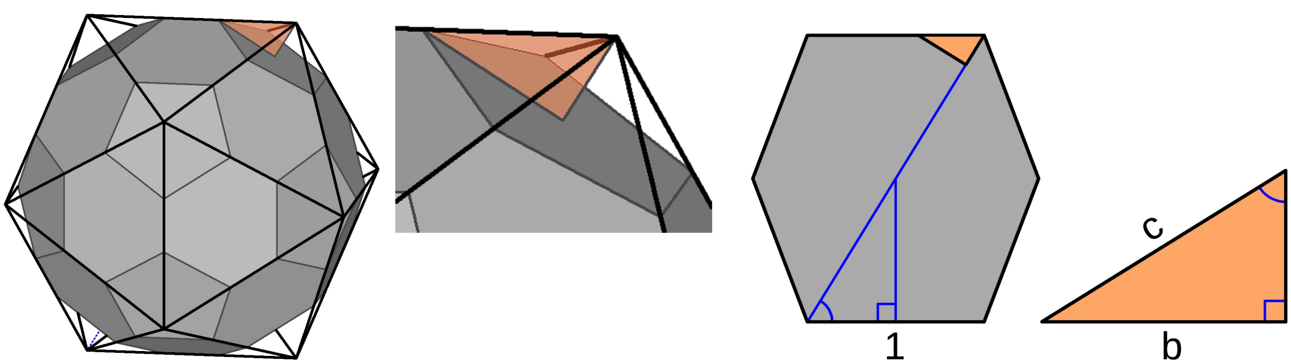
A few months later I performed a similar process to create my Equidistant Truncated Icosahedron. See the "How I Developed This Design section of the 32-Panel chapter". While the Equidistant transformation is not important for geometric reasons with this many panels (the ball will be very round in any case), the similarly-sized panels **improve the appearance of color arrangements that do not distinguish between the two shapes**, creating more uniform-looking stripes and swirls, for instance. In the "Five Swirls" arrangement below, the swirls are composed of both pentagons and hexagons (or triangles), and they have a more uniform width and better appearance when the two panel shapes are the same size. The smaller, footbag-style hexes and the larger, equilateral hexes both produce poorer swirls, and the triangles do not really work at all.

The swirl arrangements, among others, look better with the Equidistant hex that is the same size as the pent.

The Equidistant design process involved, in short, solving hypothetical right triangles that defined the position and circumradius of the Equidistant face in relation to the Platonic polyhedron from which the Archimedean polyhedron was derived. The illustrations below are from the respective chapters and show those triangles.



Diagrams illustrating the **Equidistant Cuboctahedron** design process.



Diagrams illustrating the **Equidistant Truncated Icosahedron** design process.

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Curved-Edge Faces to Approximate Spherical Polyhedra

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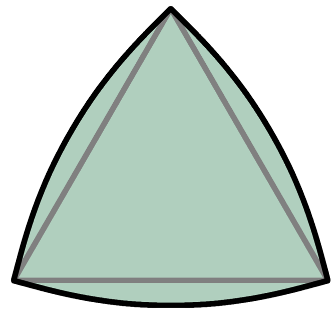
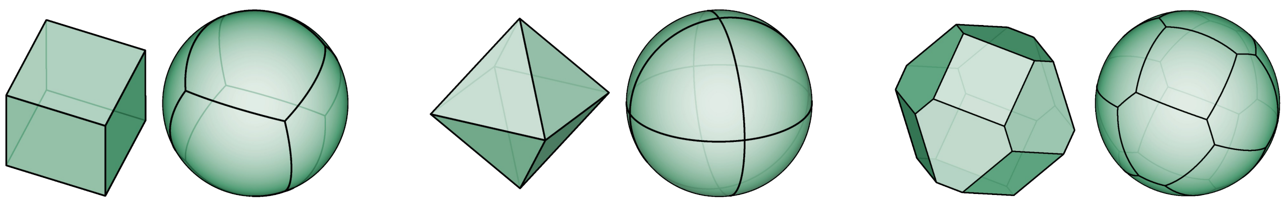
Shortcut to the Tangent-Chord Angle Theorem mathematical discussion

Introduction

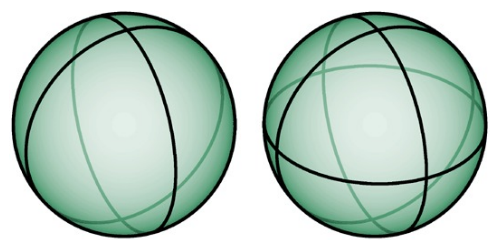


Polyhedra with few faces or long edges and sharp vertices will not produce a smoothly round ball. In those cases the edges of the panels must be curved. The curves widen the corners to produce “flat” vertices where they join together (flat at the vertex itself rather than pointed, but roughly spherical around it due to the curved edges), give the seams a circular shape around the ball, and allow the panel faces to bulge out into a more spherical shape. **This section discusses how to design the curvature for polygons to produce smoothly spherical balls** (as far as my knowledge and experience extends).



Examples of polyhedra beside their spherical forms. The spherical forms can be approximated in cloth balls by curving the panels’ edges.

Motivation: Redesigning the octahedron panel shape



Until 2013 I had no theory for designing polygon curvatures, and so I originally designed my octahedron panel shape intuitively, by using the circular curve radius from my 4-panel orange peel ball pattern, since the two designs are so closely related (the octahedron could conceptually be formed by adding a seam around the equator of an orange peel ball as shown on the right).

In February, 2015 I found a discussion thread on Reddit in which a contributor named ds300 recommended my juggling beanbag guide (the first edition), but advised against using my octahedron pattern because **the triangles were too steeply curved**[29]. The fabric he used, Ultraleather, was evidently more sensitive to the panel shape than denim, which is what I had used. He recommended instead Marylis Ramos’ pattern[30].

I had already been noticing a minor problem in the shape of my panel. **The angle at the corners was too wide for four of them to fit together** in my attempted paper model. Also, it did seem that the vertices on the beanbag were a little too flat, which (as I realized after reading ds300’s comment) is the same as the curvature of the seams being too steep. So I set about redesigning my shape.

In 2013 or so I had read an article on spherical geometry[31] which explained that **for polygons to form a sphere, the sum of the angles meeting at each vertex must be 360°**. This was the principle on which I needed to base my new panel shape.

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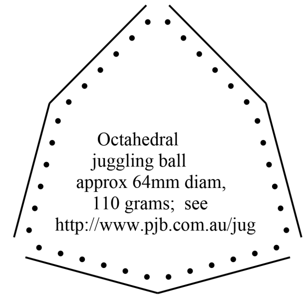
29 https://www.reddit.com/r/juggling/comments/2l4pwe/making_your_own_beanbags_some_advice_and_creative/. See 2nd comment.

30 Ramos’ two-part PDF pattern collection is titled “Sewing Patterns for Jugglers”. The 8-panel pattern is on the fourth page of her Orange Segment Series PDF. It is an excellent pattern and served as the basis of comparison for my new design.

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

The octahedron has four 60° corners meeting at each vertex, so the panels' corners must be widened to 90°. A quick and easy way to do this is to divide the triangles' edges into two, forming a new, blunt corner in the middles, so that they meet at 90° at the primary corners. This is what Peter Billam did[32] for most of his patterns (his octahedron pattern is shown on the right). This would not form a good enough ball to satisfy me, though. I wanted to use curves.



So I had to research a method of calculating arcs that form specified angles to a polygon edge[33] (technically, it is the tangents to the arcs that produce the angle). **The solution I eventually found through my research was a theorem concerning the angle between a chord and a tangent[34]**. I will demonstrate its use farther on in this chapter.

Importance of an empirical/trial-and-error approach in designing panel curvature

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I learned through redesigning my panel shapes that **strictly using math and theory to design them is not an effective approach** (at least not with any of the math I know). I tried the 90° arc corner in 2015 and the resulting beanbag made with denim was so angular that I considered it a failed design.

When I recovered from my discouragement and returned to this hobby in 2020 to write the Second Edition guide, I decided that I was going to **use extensive trial and error rather than pure math, and experiment with steeper arcs**. I was inspired to do this by another commenter in that Reddit thread, peter-bone, who pointed out that fabric stretches and distorts in complex ways to approximate a sphere that can't be predicted mathematically. He said that the best patterns he has found were derived through trial and error. **Math could enable me to calculate discrete, systematic, and reasonable arc experiments, but only finished balls could show which arc worked best.**

To determine if an arc is producing the proper ball shape, roll the ball around in your hand to let it assume its natural shape and then **hold it up in front of a bright light or window to examine the shape of its profile**. Look especially at the seams and vertices, since they are what you can control.

If the design has continuous, circumscribing seams like the octahedron, they should form perfect circles, with no flatness or prominence around the vertices or along the seams. For a design like the cube, hold the ball so that two opposite seams are in profile. Observe whether the seams' curvature, if continued, would pass exactly around the ball's ideal sphere, or would pass far outside the sphere (forming too large a circle), or if it would collide with the sphere and run inside it. The latter means it is too tight a curve and the vertex is beginning to be pulled inward. **You can also gently and repeatedly toss and roll the ball in your hands** and feel for prominences, angularity, or other deviances from a smoothly spherical shape.

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32 "How to Make Leather Juggling Balls" by Peter Billam: ~~http://www.pjb.com.au/jug/leatherballs.html~~ (now offline, except in the Internet Archive, and in my personal archives: http://web.archive.org/web/20231105094249/https://pjb.com.au/jug/leatherballs.html)

33 At this time I did not know about Bézier curves or have a tool with which to draw them, so my only option was to use circular curves. Even after I learned of them, I preferred circular curves because the original purpose of this document was to provide mathematical definitions of beanbag pattern shapes so anyone could draw them at any size, or modify their design. Circular curves are easy to define and duplicate, even by hand. Bézier curves are not. But I later decided that, since the circular curves work very well for all but the orange peel ball, I can provide definitions for the circular patterns but use Bézier curve modifications of them for my own Ready-to-Print patterns, and describe how to produce close approximations of the modified curves.

34 http://www.regentsprep.org/regents/math/geometry/gp15/circleangles.htm see #3 [EDIT: This page has changed and the tangent-chord angle link is unavailable. But the theorem can be found elsewhere.]

I found through my experimentation that, **to a moderate extent, the vertex angle sum can be increased beyond 360° and still produce a proper sphere due to the forgiving nature of cloth.** In the case of the octahedron (as well as most of my other designs), I found that **a steeper arc than that which produces the mathematically correct angle works better due to the need for a higher apex**. So did Marylis Ramos in her octahedron design, apparently. Her curve is approximately matched by an arc producing a 96° corner, though her curve levels out slightly at the ends, forming what I assume to be 90° corners.

Curve shape: Circular arcs versus Bézier curves

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The shape of the curve is another aspect of the design that requires experimentation. Peter-bone went on to say that **some of the best panel designs have edges that are not circular arcs**. I, too, have noticed that some of the most precise-looking patterns, at least for the orange peel ball, appear to use Bézier curves that level out a little as they approach the corners to produce a narrower angle than a circular curve would (or, to describe it another way, they bulge a little extra around the middle to produce a higher apex). Ramos' octahedron and orange peel ball patterns both exhibit this.

Non-circular curves can be made to both reach the necessary apex height and produce the correct corner angles since each attribute can be controlled independently. But they are more difficult to design, must be drawn in a CAD program (or sketched by hand), and are not easily definable and reproducible.

The orange peel balls require curves that are very much non-circular to form good spheres. I do not know of any branch of math that can predict the exact nature of the curves that are needed, so I had to try many different arbitrary curvatures for both the 4-panel and the 6-panel version to find the optimum panel shapes. The process was tedious and difficult.

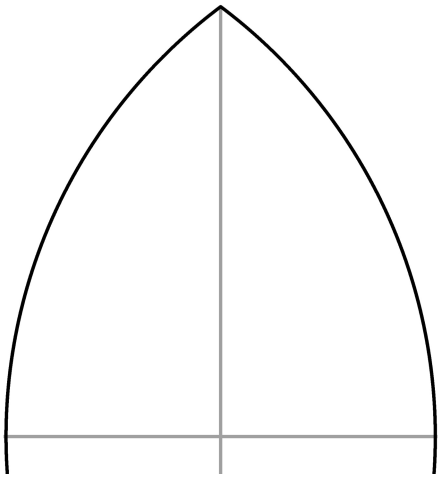
For the polyhedral panel structures, circular curves work very well due, again, to the forgiving nature of cloth. Their benefit is that they can easily be defined mathematically and easily drawn with a simple compass or circle tool in a computer app. In fact, the alteration to the circular curves to produce the correct corner angle is so minuscule (see the octahedron curve comparison on the next page) that the resulting improvement to the beanbag shapes is at most barely perceptible and is probably insignificant to most people and with most fabrics (see my account of my experiments with the octahedron's Bézier curve in the Spherical Octahedron chapter document.)

Generally speaking, **to design a non-circular curve**, you would **calculate the angle for the corner of the panel** such that the sum of corners at the bag vertex is 360°, **determine the apex height needed** to produce a circular seam profile on the finished bag (probably through trial and error), and then **draw a carefully shaped curve that meets both criteria**. **I discuss my method of doing this**, with illustrations, for the Orange Peel Ball and the Octahedron in their respective chapters.

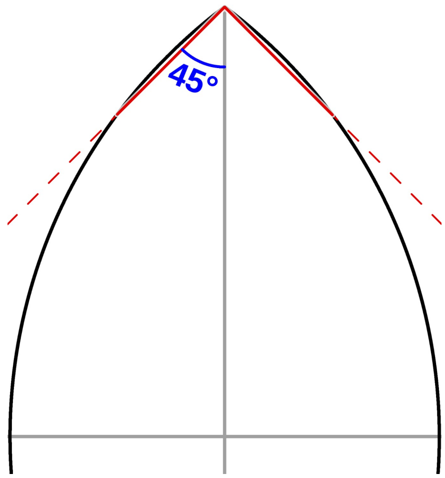
The method I used, and summarize in the illustrations below, is to **draw an arc that has the required apex height** (in my case this is the arc I determined to be optimal when developing the circular pattern shapes), **draw a straight line for the angle at the corner**, and then **draw a curve that gently merges from the line into the arc**. The curvature can be difficult to get right, however, and so may require experimentation.

The series of three illustrations that follows is for my orange peel ball pattern, but the process would be similar for any panel shape. The orange peel pattern's arc tangent angle is 53.13°, and the adjustment to

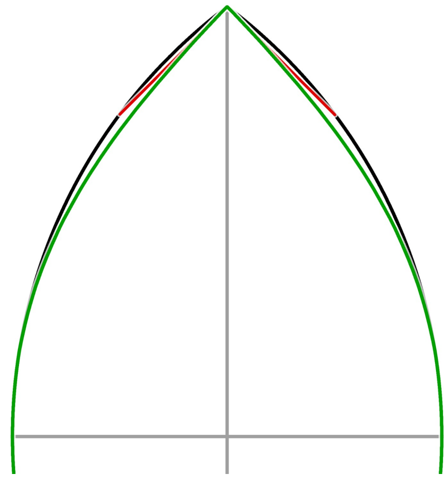
45° makes a big difference. As shown in the octahedron pattern illustration, though, the difference between the much shallower 18° tangent angle of the arc I used and the correct 15° is very small. The adjusted curve for that pattern is hardly worth designing except for a perfectionist.



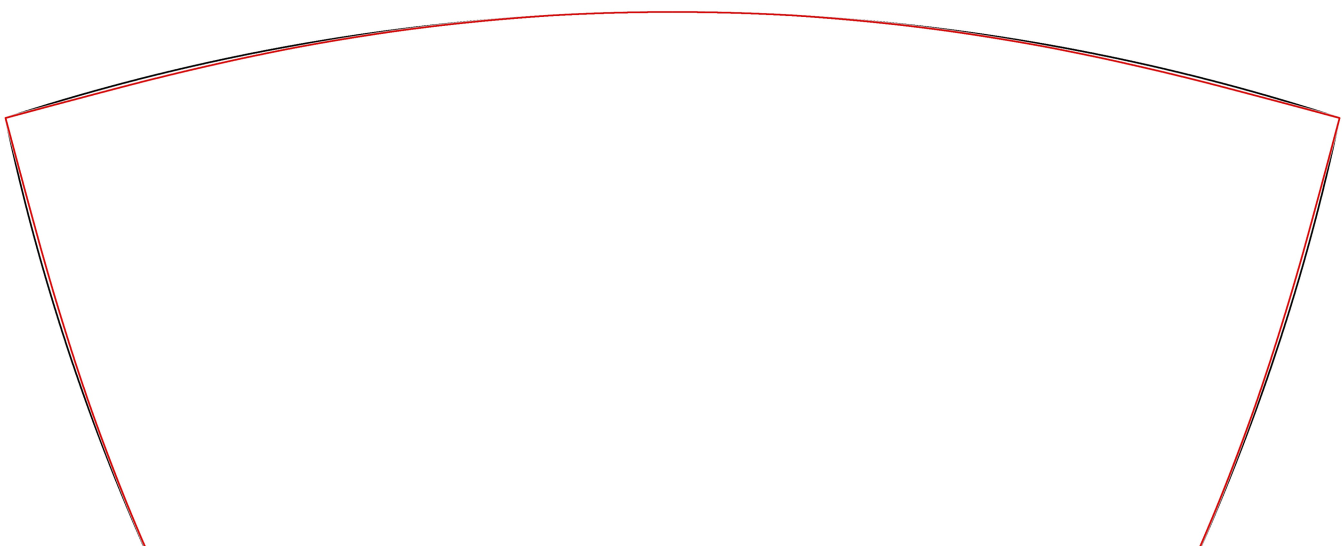
4-panel orange peel shape with circular arcs producing the necessary apex height (center to the middles of the arcs).



Four corners meet at the vertices of the ball, so each must be 90°. So draw lines at 45° on either side of the midline as guides.



Draw a curve that starts at the same angle as the guide line and gently curves away from it and merges into the circular curve.



My octahedron Bézier curve (red) compared to the circular curve (black). They are nearly indistinguishable unless magnified.

To design an ideal curve for a panel, **you must make it neither too shallow nor too steep throughout the entire curve, and the curvature must not change too abruptly**. An overly shallow curve, either producing too narrow an angle at the corner or too low an apex height, can make the bag's vertices prominent enough to be felt, and make the seams angle steeply enough from them to form a noticeably angular shape (except for high panel-count designs, or when using a stretchy fabric). A curve that is too steep at the corner, producing an over-wide angle, can make the bag's vertices flatten or even pucker inward since a vertex sum of greater than 360° cannot fit together without distorting the fabric. Too great of an apex height can cause the seams to bulge out too far, making the seams more prominent than the vertices. If the curvature changes too abruptly, such as when rounding the apex, the ball's seams will not have a circular profile.

Through trial and error, and experimenting with different fabrics, the crafter must **develop a curve that balances the vertices with the seams so that neither is too prominent**, and makes the bag as smoothly spherical as possible.

Applying the tangent-chord angle theorem

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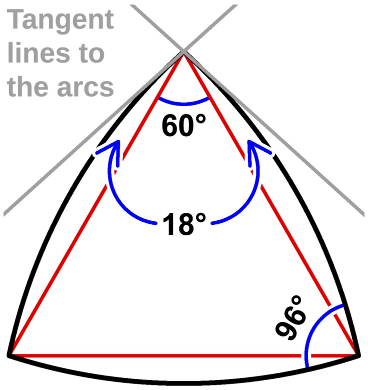


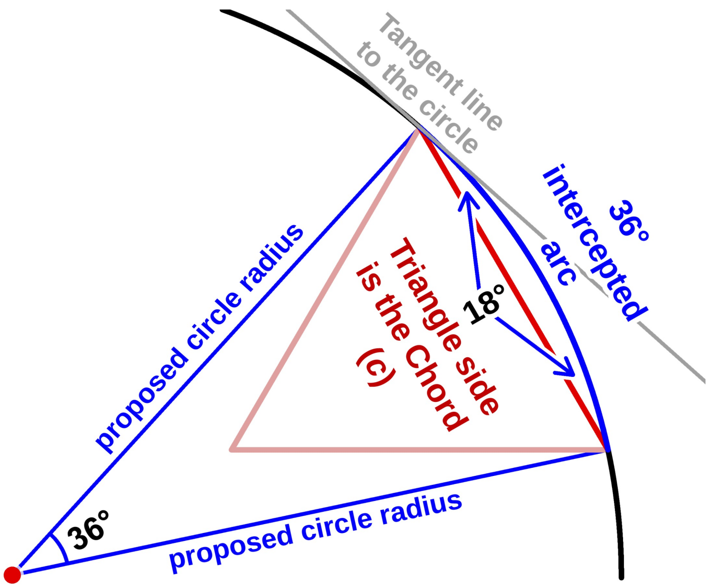
To calculate the circular arc whose tangent will produce a specified angle to the edge of a polygon, use the tangent-chord angle theorem. I will demonstrate by designing the 96° corner I use for the octahedron panel. (If you follow along with a calculator, be sure it is set to Degrees, not Radians.)

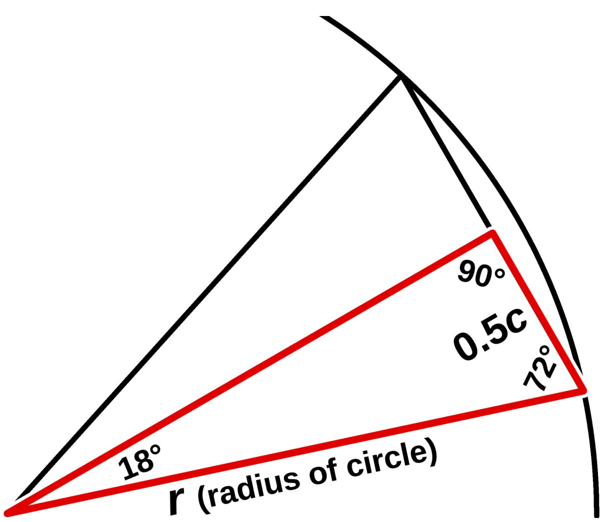
A tangent is a line that intersects a curve at only one point, and it will be at the same angle, mathematically speaking, as that point on the curve. **A chord is a line that intersects two points on a circular arc**. In this case the chord is the edge of the polygon (a triangle in the octahedron example). So what is needed is a circle such that, when it intersects both ends of the polygon's edge, a line tangent to it at the corner of the polygon will form the desired angle to the edge.

The first step is to calculate the required angle between the arc tangent and the polygon edge. That angle in this case is 18° (subtract the equilateral triangle's 60° from the 96° target corner angle and divide the result by 2, since both sides of the polygon's corners will have matching arcs).

The tangent-chord angle theorem states that an angle formed by an intersecting tangent and chord whose vertex is on the circle is ½ of the intercepted arc. In this case I already know the angle of the tangent and chord: 18°. Thus, the intercepted arc is 36° as indicated in blue in the illustration. If I then draw two radius lines from the endpoints of the chord to the center of the proposed circle, I know that the angle at which they meet is also 36°.

I can now form a right triangle from half of the triangle formed by the radius lines and solve it for the radius, *r*, expressed in terms of the triangle's edge length, *c* (the chord).





The formula in bold (solved for *r*) has been of great use to me (again, be sure to use Degrees, not Radians).

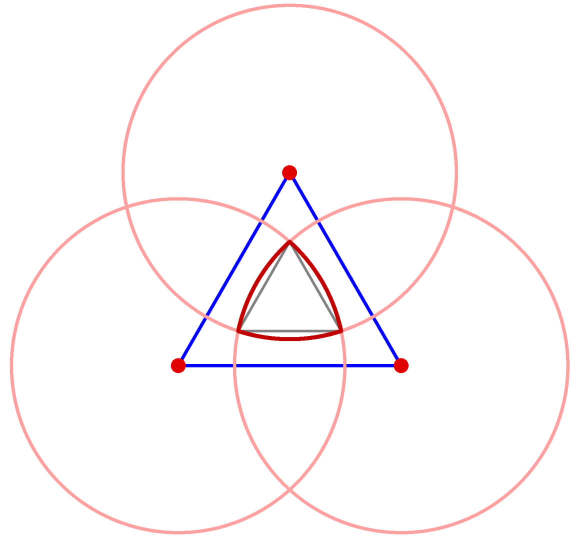
$$\sin\theta = \frac{opposite}{hypotenuse} \;\blacktriangleright\; \sin 18° = \frac{0.5c}{r} \;\blacktriangleright$$

solved for *r*: $\mathbf{r = \dfrac{0.5\,c}{\sin 18°}}$ or, generically, $\mathbf{r = \dfrac{0.5\,c}{\sin\theta}}$

To solve for the angle when the radius is known, by the way, the formula is

$$\theta = \arcsin\left(\frac{0.5\,c}{r}\right)$$

To draw a circular triangle I need three circles, and so I need to calculate the distance between the centers of those circles that will result in the desired pattern size. That distance will be proportional to the circles' radius so as to form the intended curvature. The circle centers will be arranged as the corners of an equilateral **guide triangle** (shown in blue) surrounding the proposed panel shape (or in the case of the tetrahedron's panel shape, the circle radius is so small that the centers are within the panel shape). **The distance between each circle center forms one edge of that guide triangle**. I will have to draw the guide triangle (or its three corners) in order to position the three circles.



Calculating the relationship between the guide polygon & arc radius, and the resulting pattern size

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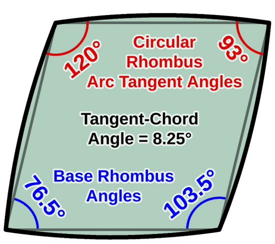
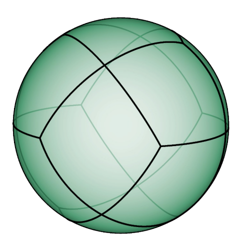
To draw a pattern of a desired size, I need a way to use that size to calculate the necessary guide triangle and circle radius. The simplest way I know of to **calculate the relationship between size of the pattern and the size of the guide triangle and circle radius that form it** is to start with a unit equilateral triangle (or whatever polygon the pattern is based on) and form the panel shape around it (actually drawing it is not necessary – only the calculations are).

The steps that follow show how to calculate this relationship, and afterward I will demonstrate how to use the results of the calculations for a hypothetical pattern. In the calculations, as previously, c represents the length of the triangle's sides (it is the chord of the circles). **All result values below are ratios of the starting side length.** (All values are rounded to six decimal places.)

This series of calculations needs to be performed for the particular curvature you choose for your pattern, because my calculations are based on the 96° pattern angle, or 18° tangent-chord angle, that I use. **This process can easily be adapted for patterns based on other equiangular polygons (it does not work for shapes with differing angles such as rhombi and kites).** For examples of some other equiangular shapes, see the "Mathematics" section of my chapter documents on the spherical cube, dodecahedron, and 14-panel designs.



Designing curves for non-equiangular polygons such as the Rhombus is more complicated, but involves some of the same math. My method for the Rhombic Dodecahedron was, in brief, to decide on a target vertex angle sum for each type of vertex (3-way and 4-way) and then calculate, with algebra, a base rhombus and arc radius that would produce those sums.



The method for calculating the distance between circle centers and the guide rectangle for the circular rhombus was much more complicated than for equiangular polygons. Rather than reiterating the process here, I will direct the reader to the Mathematics section of the **12-Panel Spherical Rhombic Dodecahedron** chapter document where the process is well-organized and illustrated.

Calculating the Relationship between the Octahedron Pattern Size and the Size of the Guide Triangle and Circle Radius That Form It

For a different base polygon, use its circumradius, apothem, and height formulas in Steps 4 – 6. Works for equiangular polygons only.

1.) Calculate the tangent-chord angle

To reiterate the first step, take the desired corner angle of the rounded polygon (96° in this example), subtract the polygon's normal angle (60°), and divide the result by 2. This is where the **18°** in the steps below comes from. As I showed earlier, this is also the angle of the right triangles formed by dividing the radius-chord triangle in half.

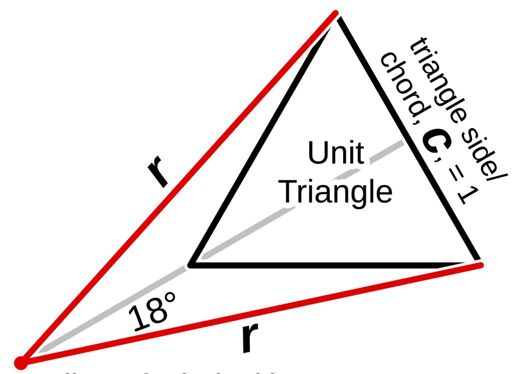
2.) Calculate the circle radius

Using my radius formula

$$r = \frac{0.5c}{\sin\theta}$$

and the 18° tangent-chord angle, the **circle radius** is

$$\boldsymbol{r} = \frac{0.5c}{\sin 18°} \approx \frac{0.5c}{0.309017} \approx \mathbf{1.618034}\boldsymbol{c}$$

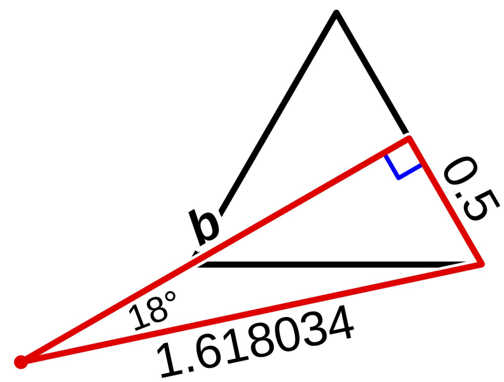


Radius of Circle (r) ≈ 1.618034

3.) Calculate the distance between the starting polygon edge (chord) and the circle center

As a preliminary step to calculating the guide triangle, we need the distance between the circle center and the edge of the starting triangle, which is the longer leg of the right triangle formed by the radius and half the chord (labeled b in the illustration). We can use trigonometry for this as I did for the radius, or the Pythagorean theorem:

$$b = \frac{0.5c}{\tan 18°} \quad \text{or} \quad \sqrt{1.618034^2 - 0.5^2}\,c \approx 1.538842c$$

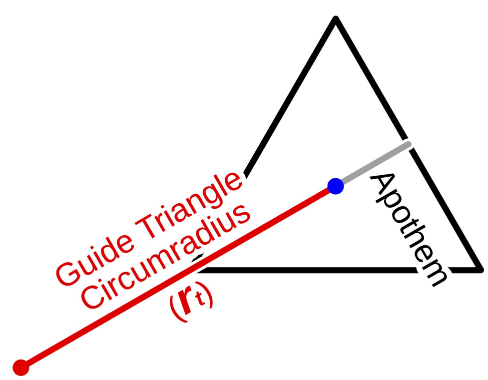


4.) Calculate the guide triangle's circumradius

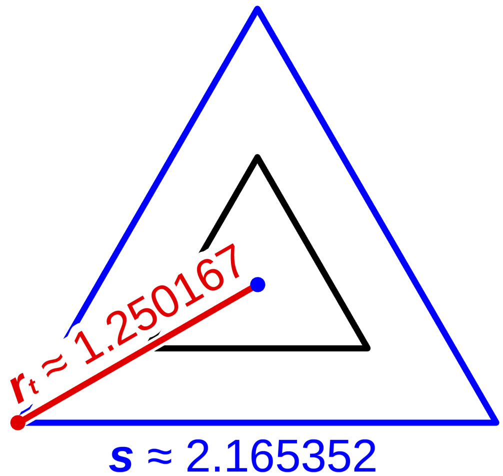
The guide triangle's circumradius (center to corner) is side b above minus the starting triangle's apothem or inradius (center to edge). (For a square, just subtract $0.5c$.)

$$\textit{unit triangle apothem/inradius} = \frac{\sqrt{3}}{6} \approx 0.288675$$

$$\boldsymbol{r_t} \approx 1.538842c - \frac{\sqrt{3}}{6}c \approx \mathbf{1.250167}\boldsymbol{c}$$



5.) Calculate the guide triangle's side length



With the guide triangle's circumradius we can calculate its side length, s, using the formula

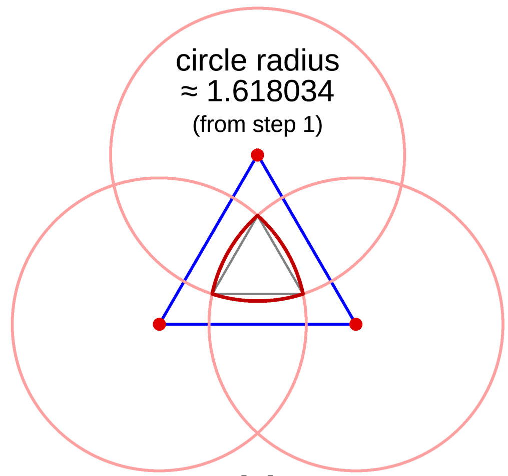
$$r_t = \frac{s}{\sqrt{3}}$$

Solving for s we get

$$\mathbf{s} = \sqrt{3}r_t \approx (1.732051)(1.250167c) \approx \mathbf{2.165352c}$$

With that we can draw the guide triangle (shown in blue).

6.) Calculate the pattern height

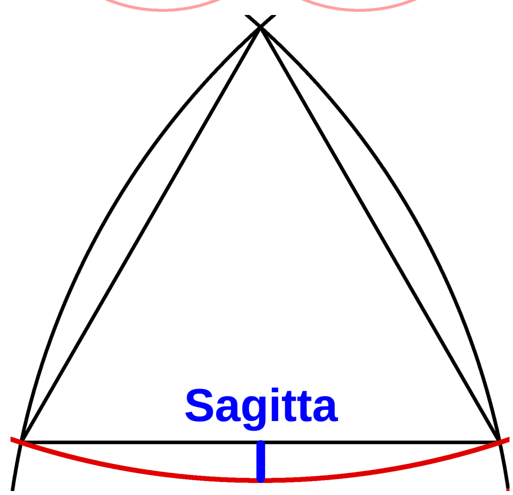


The upper image on the right shows how the guide triangle is used to draw the panel shape. When drawing the actual patterns, the inner, starting triangle is not needed.

The height of the pattern is the height of the inner triangle plus the **sagitta**, or the **height of the curve's apex over the chord** (triangle edge). The sagitta is simply the arc radius minus the right triangle's side b that I solved for in Step 3 as part of calculating the guide triangle's radius (side b is the distance between the circle center and the chord).

$$\textit{unit triangle height} = \frac{\sqrt{3}}{2} \approx 0.866025$$

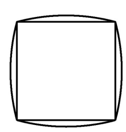
$$\textit{sagitta} = r - \frac{0.5c}{\tan 18°} \approx 0.079192c$$



The height of the panel, then, is

$$\mathbf{h_p} \approx \frac{\sqrt{3}}{2} + r - \frac{0.5c}{\tan 18°} \approx 0.866025c + 0.079192c \approx$$
$$\mathbf{0.945218c}$$

For a symmetrical shape like a square or hexagon, remember to add the sagitta twice.



The result of these calculations is that we have the size of the pattern expressed in terms of its inner triangle size, and we have the size of the guide triangle and circle radius expressed in the same terms. That gives us their ratio to each other, allowing the guide triangle and circles to be calculated for any given pattern size.

As an example, I will show how to use these values to create a 2-inch high pattern (forming a ball with a circumference of 8 inches and a diameter of 2.55 inches).

First, divide the pattern height, 2, by its ratio to the inner triangle side length, **0.945218** (from Step 6), to get our pattern's inner triangle side length: **2.115915**

Then multiply that by the ratio of the inner triangle to the guide triangle, **2.165352** (from Step 5), to get the guide triangle's side length: **4.581701** (or use the ratio of its circumradius from Step 4 if you need that instead). Then draw the guide triangle.

Now take the inner triangle's side length from the first calculation, **2.115915**, and multiply it by its ratio to the circle radius, **1.618034** (from Step 2), to get our circles' radius: **3.423622**. Then draw the three circles, yielding the finished pattern.

Remember that these values only apply to the curvature that forms the 96° corners. They would need to be recalculated for the actual curvature that will be used in your pattern.

Arc Length Formula

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The arc length formula can be useful for a few reasons. For some panel structures, such as the dodecahedron, in order to **calculate the pattern size needed for a desired ball size**, you will not only need to know the height of the pattern, but also the length of its edge arcs, since the ball's circumference is composed of both. If you are using leather, this formula can help you **evenly space awl holes** along the panels' edges. It can also be used to calculate the beanbag circumference at the seams, or the length of stitching you need to do if you want to calculate the length of thread needed, or have another use for that statistic.

If you know the tangent-chord angle of your panel, you can simply multiply it by 2, which is the amount of arc intercepted by the chord, and the total additional angle at the panel's corners (36° in my example), and use that for θ in the following formula. r is the radius of the arc.

$$L = \frac{\theta^\circ r \pi}{180}$$

If you do not know the angle, use the formula below. As before, c is the chord, or length of the polygon side spanned by the arc, and r is the radius of the arc. The formula assumes you are working with degrees, not radians.

$$L = \left(2\arcsin\left(\frac{0.5c}{r}\right)\right) r \times \frac{\pi}{180}$$

I derived these formulas by using the arc length formula $L = \theta^\circ r$ from Wikipedia where θ is the angle in radians subtended by the arc. For the second formula I used my edge arc radius formula from earlier and multiplied it by 2 to get that angle:

$$\theta = 2\arcsin\left(\frac{0.5c}{r}\right)$$

Since the arc length formula uses radians, I added the $\frac{\pi}{180}$ factor to convert degrees to radians. If you are working with radians already, omit that.

Here is an automatic arc calculator I found: http://www.handymath.com/cgi-bin/arc18.cgi?submit=Entry

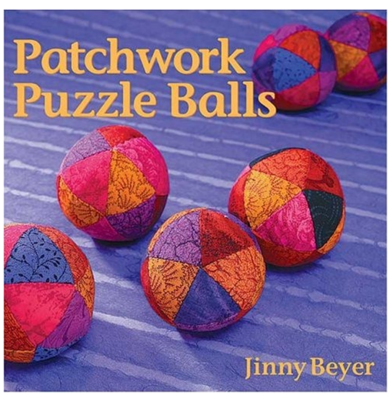
APPENDIX I – FABRIC BALL PROJECT IDEAS

There are many published ideas for fabric ball projects. Following are some that particularly interested me. These balls are stuffed with soft stuffing, not pellets. Some of them use types of polyhedra I do not provide chapters for, but tutorials and patterns for them can be found on the internet, or in book form.

Here is a tutorial I just found (11/12/2020) for geometric and puzzle balls. The image to the right comes from this article. The article includes links to tutorials by other authors for each kind of ball:

"Soft Toys & Amish Puzzle Ball" by Sew, Jahit – www.sewjahit.com/post/soft-toys-amish-puzzle-ball

Patchwork Puzzle Balls by Jinny Beyer, and Related Balls



I have not read this book, but I have found many references to it and many beautiful works inspired by it. Following are some of them.

Fun with Jinny Beyer quilts/fabric and ideas – www.pinterest.com/coachtinaj/fun-with-jinny-beyer-quiltsfabric-and-ideas.

www.pinterest.com/pin/515943701033625403/

The balls on the upper left are Icosahedra (20 triangles) and the ones on the lower left appear to be Truncated Octahedra (6 squares, 8 hexagons) with each hexagon divided into six triangles. The balls above are Truncated Cuboctahedra (12 squares, 8 hexagons, 6 octagons).


Dodecahedron


Truncated Octahedron


Icosahedron

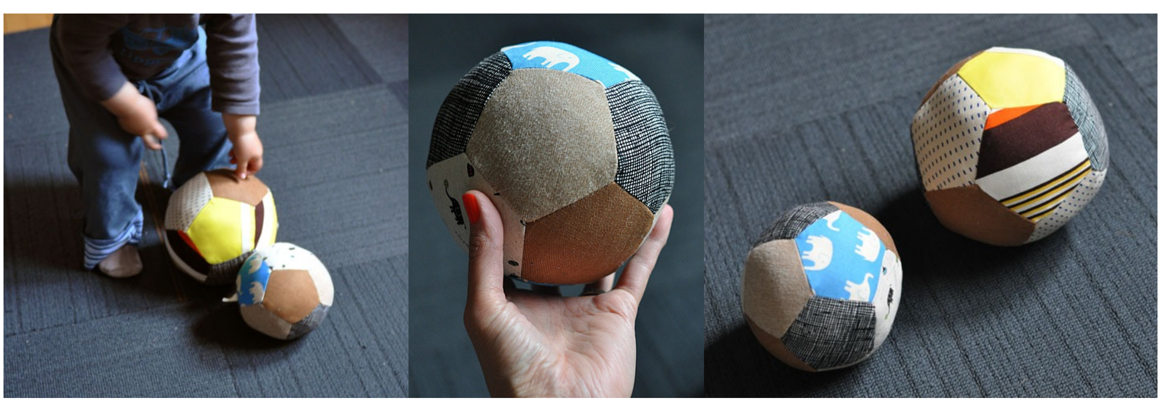

Rhombicuboctahedron


Rhombic Triacontahedron


Icosidodecahedron

Balls inspired *Patchwork Puzzle Balls*, from an article titled “Pieced Balls” at www.personal.psu.edu/axd2/quilt/qlt36.html. These balls are all three to five inches in diameter and I assume they are intended to be used as children’s toys or perhaps as decorative centerpieces. I have chapters on each of these designs except the icosahedron.

Large, corduroy toy balls by Crafty Panties (patterns from *Patchwork Puzzle Balls*). These are icosidodecahedra, for which I provide patterns and instructions in the 32-Panel chapter. The forum thread where I found these three photos seems no longer to exist.

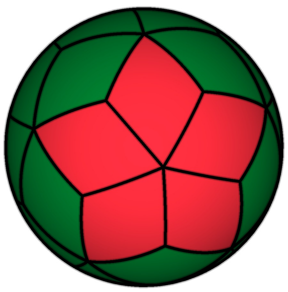


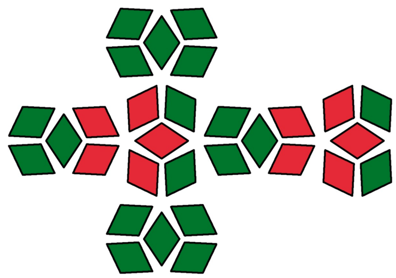
<http://andothersillythings.blogspot.com/2011/05/pentagon-colorful-fabric-balls-tutorial.html>

Random fabric scrap balls by Jennifer Murphy. These are dodecahedra, for which I provide patterns and instructions in the 12-panel spherical dodecahedron document.

Child-Safe Christmas Ornaments

Idea and photo by "The Shishi Girl" from http://shishigirl.blogspot.com/2008/12/basic-geometry-ii.html. This is a six-panel orange peel ball made with felt. My Orange Peel Ball chapter provides patterns and instructions for both a 4 and a 6-panel ball.





The 30-panel rhombic triacontahedron would make a lovely Christmas Ornament with either a poinsettia-like color selection or a star in a night sky. I have an instructional chapter on this structure.

Ball-Based Toys

These are two toys I invented based on ball designs. I have an essay and assembly diagrams for the Turtle Ball in the 32-panel chapter document, in the last section titled "Turtle Ball". The Poké Ball is a modification of a 14-panel structure. There is a section about that at the end of the 14-panel Equidistant chapter document called "14-Panel-Derived Poké Ball".

Activity Ball for babies by ElmaRi from www.lovilee.co.za/2012/diy-activity-ball/.

Montessori (or Amish) Puzzle Ball

This is an interesting ball design that is often made to stimulate babies' minds and fingers, but is also used decoratively.

www.thekavanaughreport.com/2017/04/montessori-puzzle-ball-montessori-baby.html

www.pinterest.com/pin/301741243779828034/

https://patterni.net/cloth-ball-pattern/

From the blog "Finding My Way – Stories from Laurel Lane" by Kathy Haynie at http://kathyhaynie.blogspot.com/2010/03/fabric-balls-craft-tutorial.html

www.pinterest.com/pin8/7679523976868090/

Other Geometry-Based Cloth Ball Designs

www.thesprucecrafts.com/quilted-fabric-star-christmas-ornament-pattern-2821348

finestdiy.com/christmas-craft-ideas/christmas-craft-ideas-9/

www.jugarijugar.com/es/pelotas-y-bolas/2999-pelota-de-tela-multi-texturas.html

www.zulily.com/p/tricorn-plush-ball-5675-21003738.html

APPENDIX II – HOW TO DRAW SPHERICAL POLYHEDRA

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I had to figure out for myself how to draw spherical polyhedra because I could find no information on the web for doing this. I decided to include instructions here for anyone else who wants to draw them. **I have developed two methods of drawing them. Method 1 is my original method, but I could not at first figure out how to make it work for the Rhombic Triacontahedron, whose vertices are not all equally distant from the center. So in May, 2022 I developed Method 2.** Then I realized how Method 1 would have to be applied to shapes like that, and added some notes about this at the end of Method 1.

The orange peel ball and spherical octahedron are composed simply of circles. To draw them, draw a circle, rotate a copy of it to create the framework of the polyhedron, and then position its center at the center of a sphere of the same size to create the skin. (Finding the center of the sphere is easier if you draw it at the origin of the axes.) The 24-face Deltoidal Icositetrahedron is a combination of the cube and octahedron, so I drew the spherical version by drawing the spherical versions of those two and combining them. The baseball design is currently too advanced a design for me to draw in 3D. I used a combination of my beanbag photo, MS Paint to overlay custom Bézier curves onto the bag's seams, SketchUp to obtain 3D shaded, colored spheres for the skin, and Photoshop to bring it all together and pretty it up.

Most types of spherical polyhedra cannot be painted on a face-by-face basis in SketchUp (at least I don't know how). I assume this is because the "circular" edges of the polyhedron, being in fact composed of many small facets, do not precisely match the faceted surface of the sphere and so the entire surface is considered one face and will always be a single color.

I color spherical polyhedra using Photoshop. I first capture a screenshot (or use the 2D Graphic export feature) and in Photoshop I use the Magic Wand tool to pull the panel edge framework into a separate layer. Then I capture screenshots of the sphere colored with each color I want to use and add those as layers to the first image. Then, using the edge framework and the Magic Wand tool, I create selections inside each panel, select the desired sphere layer, copy those sections of that sphere, and paste them as a separate layer. I do that with each sphere and end up with sections of spheres corresponding to the panels of the ball, resulting in a multi-color ball. I also use Photoshop to make the edges thicker by using the Stroke attribute of the framework layer.

For any spherical polyhedron, I recommend using circles with a large number of sides so you get a good curve. However, if you use too many sides, the sphere will take a long time to generate unless you have a very fast CPU. I use 90 (360/4). If the lines of the polyhedron are partially hidden within the sphere, this is probably because the sphere is a tiny bit larger than the polyhedron due to rounding or to the straight facets of the arcs extending beneath the surface of the sphere at their middles. In this case make the sphere slightly smaller.

Method 1: Build the Spherical Framework Onto the Polyhedron

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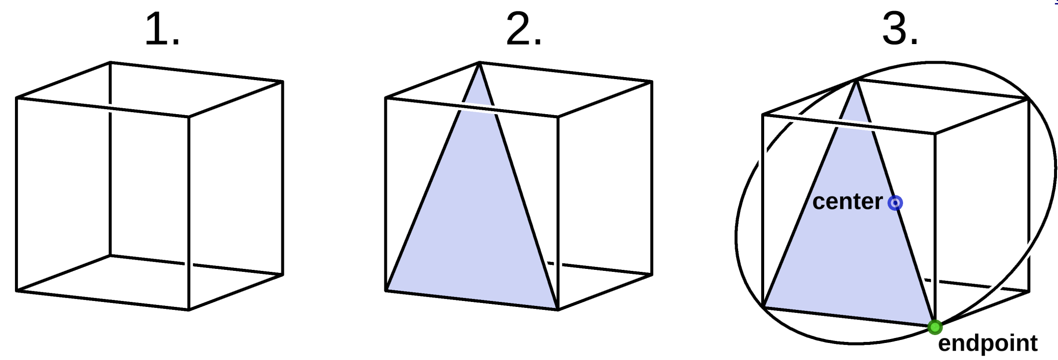
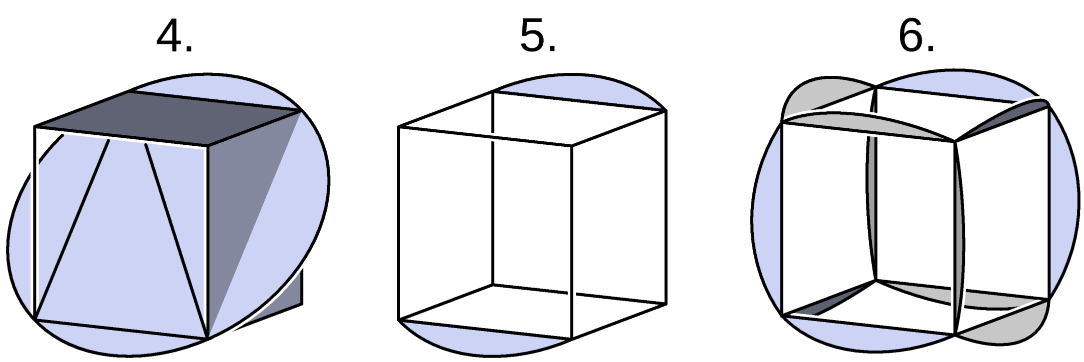
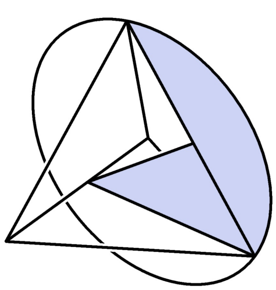


These instructions apply to SketchUp Make, but can be adapted to other CAD applications.

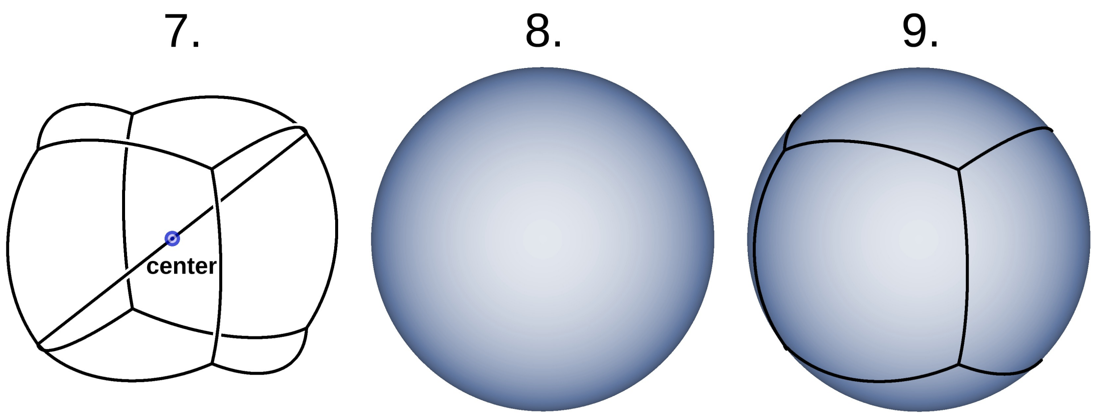
1. **Draw the polyhedron** (instructions for drawing common polyhedra can be found online). Make sure it is fairly large because later you will have to draw a matching sphere and SketchUp has (or at least had) trouble rendering very small spheres when I set the circle's side count very high, leaving holes at each pole. Erase the face color, leaving just the edges.
2. Draw a line from one corner to the diagonal opposite corner through the center of the solid and then draw a second line to complete a triangle. **This temporary face is just for aligning the Circle Tool.** The second line that completes the face does not need to extend from corner to corner as I have drawn it. Just a tiny triangle will do if you know how to hold a tool's alignment.
3. Select the Circle Tool, align it with the triangular face, and **draw a circle from the center of the first line (the triangle's hypotenuse, which is the center of the solid) to any of the corners on the same plane with the circle.***



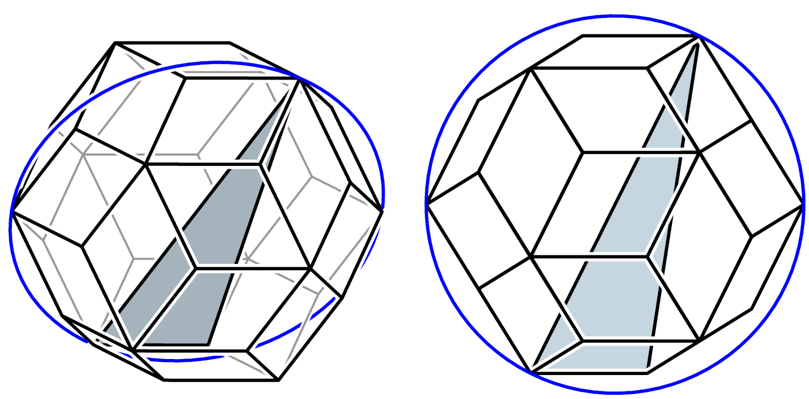
4. When you draw this circle you will get several unintended faces as shown in figure 4.
5. Erase the superfluous faces, excess circle portions*, and the temporary triangle.
6. Repeat these steps for each pair of opposing edges until you have something like figure 6.



For an asymmetrical polyhedron such as the tetrahedron, draw the first line from edge center to opposite edge center as shown on the left and then complete the triangle to form a face. In this case you will create only one edge arc instead of two and the rest of the circle will have to be erased



7. If you hover the Move tool over one of the arcs, SketchUp should provide a snap point for the center of the framework. If this does not work for some reason, draw a line through the center as in Step 2 (or leave the last one you drew) so that you can **find the center of the framework**. You may, but it is not necessary, erase the straight edges of the original polyhedron leaving only the spherical version behind as shown in figure 7. Draw the line before erasing the original polyhedron because otherwise it will be difficult or even impossible to find the exact corners or edge centers.
8. **Draw a sphere at the origin of the axes** that has the same radius as the spherical polyhedron (half the length of the line from the previous step). There are instructions online for drawing spheres.
9. **Position the center of your spherical polyhedron at the origin so it is exactly centered within the sphere.** You will need to hide the sphere's faces first so SketchUp will allow you to position the polyhedron at the origin rather than on the surface of the sphere (**View** menu ► **Face Style** ► **Wireframe**). Change the Face Style back to Shaded to produce the spherical polyhedron.



***This method works differently for polyhedra whose vertices are not all the same, and therefore are not the same distance from the center, such as Catalan solids.** As shown by the **Rhombic Triacontahedron** on the right, the circles do not intersect both ends of any edge, so the entire circles must remain until all circles are drawn. Then the extraneous arc segments can be erased. The circles each intersect four 5-way vertices but span above the 3-way vertices. The spherical 3-way vertices will be formed by circles intersecting above those vertices.

Method 2 follows a related procedure. Step 4 of the rhombic triacontahedron instructions shows what all the circles look like together, and the subsequent steps show how to erase the unneeded arc segments, and what the result looks like.

Method 2: Build the Spherical Framework Without a Polyhedron

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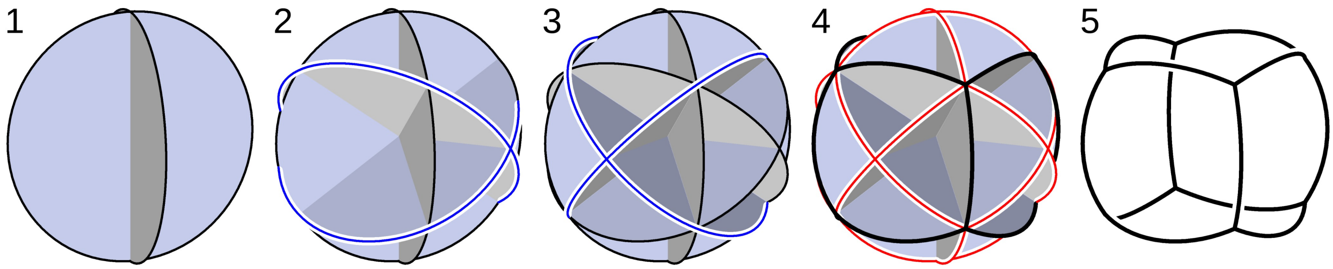
In this method, circles are positioned for all edges of the polyhedron using angles of rotation rather than a reference polyhedron, and then the extraneous arc segments are erased. Figuring out the angles of the circles and how to rotate them around the correct axis can be challenging. This method could be combined with the first method as discussed in the Rhombic Triacontahedron notes above so that there is a reference polyhedron to aid in positioning the circles and in erasing the correct arc segments.

I will demonstrate this method with the cube first for simplicity, and then with the rhombic triacontahedron.

These instructions apply to SketchUp Make, but can be adapted to other CAD applications.

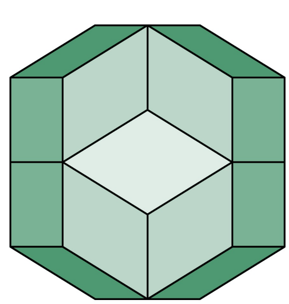


1. **For the cube, create two circles at right angles to each other.** I recommend making this pair of circles its own independent "Group" so it does not attach to the copy and you can more easily select it to produce the second copy. (Select the circles and either right-click them or open the Edit menu and select "Make Group".)
2. **Rotate a copy of the pair of circles 90° down one quadrant.** That axis of rotation will be easier to achieve if you first rotate the initial pair at 45° to the axes so the rotation is aligned with an axis.
3. **Rotate a copy of either pair 90° into an adjacent quadrant.** This completes all arcs for the cube.
4. First, if you made each pair of circles its own independent Group, select all groups and Explode (ungroup) them so the circles attach to each other. Then **erase the arc segments that are not part of the cube (shown in red)**. If some arc segments cannot be erased without also erasing the part you want to keep, see Step 5 of the next set of instructions for help.
5. **This results in the same arc framework produced by the first method.**

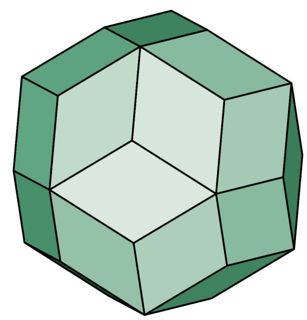
Continued on the next page.

Following is how Method 2 is used for the rhombic triacontahedron. The instructions can be adapted for other solids. First, note that at each profile aligned with a face (as shown in the first image below) there are four edges that are aligned with the same plane as that face (the diagonal edges in the illustration). The circular version of these four edges is formed by a single circle around the polyhedron.

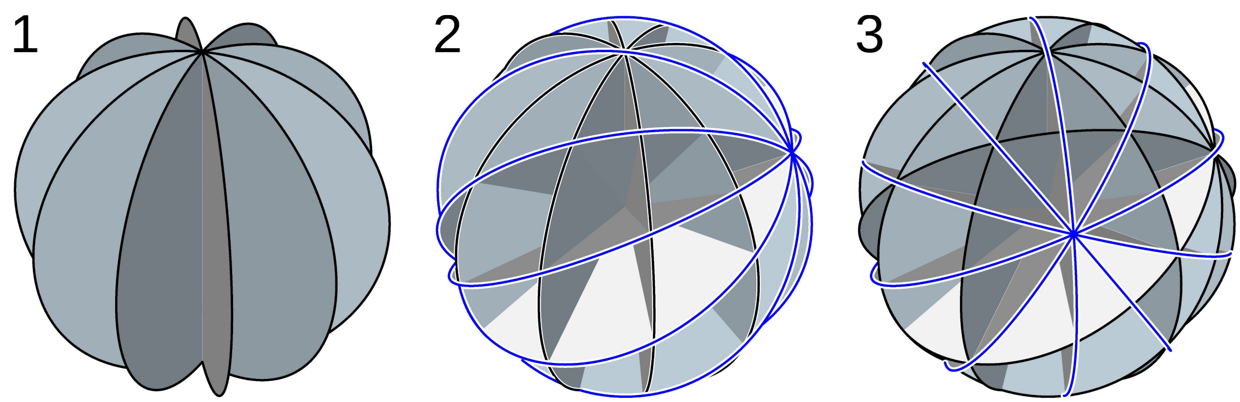
That circle crosses four 5-way vertices. If I create five circles that intersect each other at equal angles, corresponding to the five edges at each of those vertices, and orient copies of that array of circles for each opposing pair of 5-way vertices on the polyhedron, I would have all arcs for the spherical version. (This did not seem so straight-forward during the few days it took me to analyze this shape and figure out how to draw the spherical version of it!)



The four diagonal edges are aligned with the same plane as the foremost face.



Slightly rotated to give some perspective.

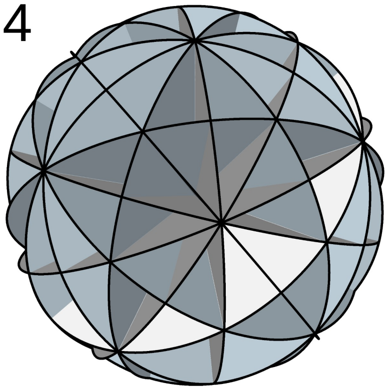


1. **Create five circles at 36° angles to each other, resulting in ten equally-spaced arcs.** I recommend making each circle its own independent "Group" so it does not attach to the others and you can more easily select entire circles. (Select a circle and either right-click it or open the Edit menu and select "Make Group".)

2. **Rotate a copy of the circles 63.435° ($\tan^{-1}(2)$, the acute angle of the rhombus) down one of the ten arcs.** Each rotated copy you make will overlay circles onto existing ones. This copy will overlay only the circle aligned with the axis of rotation. The next copy overlays two circles, the third overlays three, and the fourth overlays four. I recommend either copying only the circles that won't overlay previous circles, or deleting the overlayed circles after rotation. This makes Step 5 easier because the overlayed arcs will otherwise break up into segments when ungrouped rather than remaining intact, selectable arcs.

3. **Skipping the next arc, rotate a second copy 63.435° down the 3rd arc.**

4



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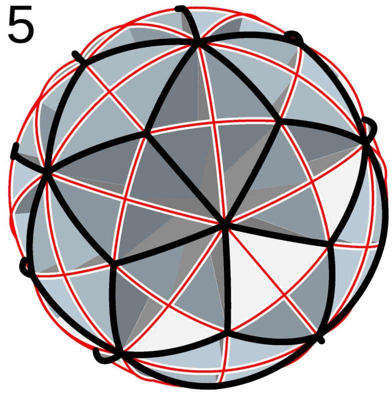

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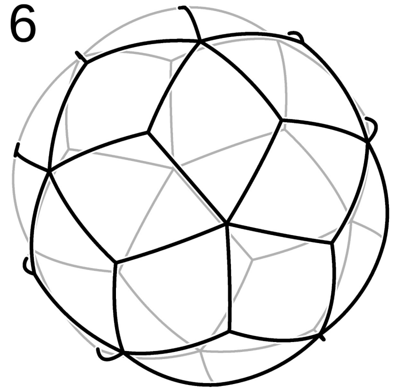
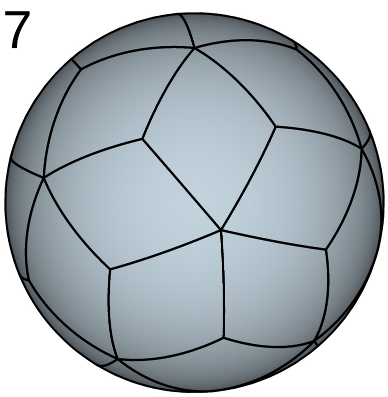
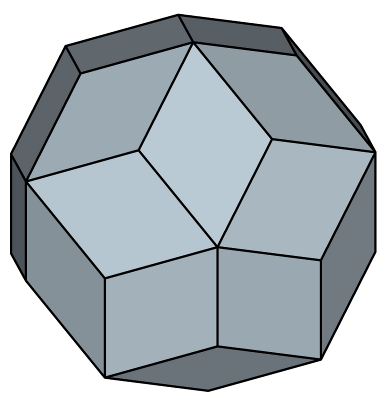


4. **Rotate two more copies along the 5th and 7th arcs.** This completes the framework.
5. First, if you made each circle its own independent Group, select all groups and Explode (ungroup) them so the circles attach to each other. Then **delete all arc segments that are not part of the polyhedron (shown in red).** These will be at every point where two arcs cross at right angles. Around each of those intersections is the rhombus/diamond shape you want. This step can be difficult, not only because the dense network of arcs can be confusing, but because, depending on how the arcs' intersections are defined by the application, some may not actually intersect and so you will delete more than the intended arc. In these cases, zoom in at the point on the arc between the part you want to delete and the part you want to keep and draw a line connecting to that point. That will divide the arc into two segments that you can select individually. You could also Explode the arc so that each facet becomes selectable/erasable.
6. **This should result in a network of arcs corresponding to the polyhedron.**

7



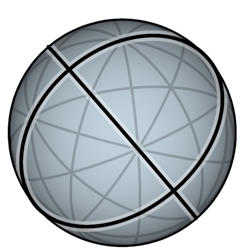


Polyhedral version for comparison

7. **Create a sphere and align its center with the center of the arc framework** to get the finished spherical polyhedron. See Steps 7 – 9 of Method 1 for more details on adding the sphere.

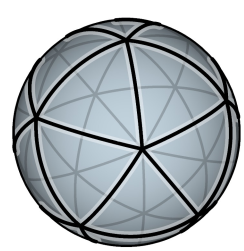
Other shapes can also be formed from this particular network of arcs:

Starting arc network



Octahedron

Dodecahedron



Icosahedron

Derivation of the Brilliant.org Logo

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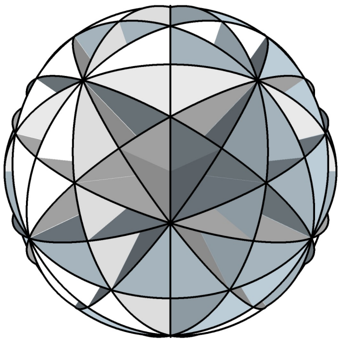
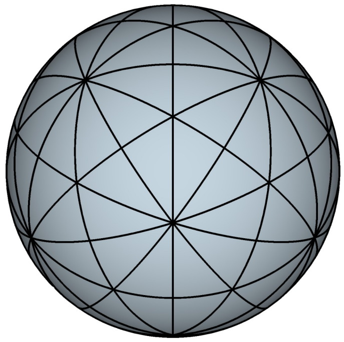
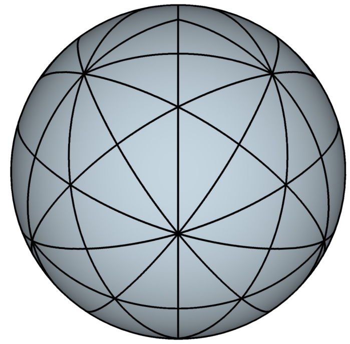
After working on the Method 2 instructions and illustrations for a few days, I happened to watch a Ze Frank "True Facts" video on YouTube, and it included a promotion for Brilliant.org, an organization that provides online tools for understanding and teaching mathematics. I had seen their ads before, but this time, because of my work creating the spherical rhombic triacontahedron, I recognized their logo design:



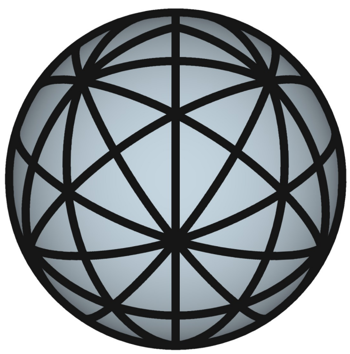
This is my framework for creating the spherical rhombic triacontahedron, rotated to a specific symmetrical view angle.



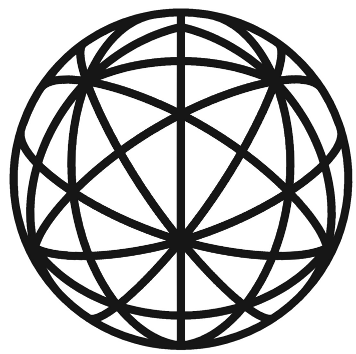
I place a sphere inside it so only the front edge framework is visible.



Here, I removed certain edges around the perimeter, changed SketchUp's camera field of view from Parallel Projection to 12° Perspective, and I imported the image into Photoshop and applied a -15 Pinch distortion.

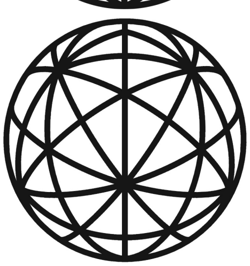


Edge framework pulled out into a separate layer and thickened



Sphere layer removed

BRILLIANT



The actual Brilliant logo above and my design below it. Mine is almost identical, but after a few hours of experimentation I couldn't get the view angle, field of view, and Pinch distortion to produce an exact match. But this was an interesting discovery and a fun little project! (Logo downloaded from https://assets.website-files.com/60148f94d54c730824522bf6/6093150385752c043ce7c0b9_brilliant%20(1).png.)

WESTMINSTER FOUNDATION FOR DEMOCRACY

While searching for the logo, I also came across this. The WFD uses the same arc network, but rotated differently and with no fish-eye distortion or omitted arcs. (Logo downloaded from https://epd.eu/home/wfd-logo-2/.)

APPENDIX III – HOW I CREATE HDR BEANBAG PHOTOS

Too long? Jump to the illustrated summary.

Setting up the photos

Capturing and editing the beanbag photos to make them look attractive is very difficult and time consuming. I do not have a light box or any photography equipment apart from a tripod and my sister's DSLR camera, so for lighting I need to use the sun along with white plastic reflector panels I took from the lids of discarded photo scanners.

Since I need to rely on the sun, and I do not have a light diffuser, I ideally need to wait until the sun is high in the sky and has some cloud cover to diffuse its light. If the sun is too low in the sky, the side of the beanbag facing away from the sun will be too dark. If there is no cloud cover, there will be sharp shadows. I am trying to achieve a photo that looks like it was captured in a light box, with even lighting across the beanbag's entire surface. Between that and needing to avoid wind and rain, these photos are stressful to capture and require a lot of patience, which I do not have much of.

To set up a photo, I begin by using a lint roller or masking tape to clean the lint and dust off the beanbag. Then I place one of my reflector panels on the porch and place the beanbag on it, and then stand two panels upright next to it, on the side opposite the sun. I hinged those two together into a right angle with adhesive tape so they will stand on their own. These three reflectors light the bottom, sides, and rear of the beanbag.

I then position the tripod over the beanbag and point the camera down at it. I adjust the angle of the beanbag, sometimes using a reference image on my phone, until it looks good in the LCD viewfinder, and round out its shape if it looks lopsided. Then I capture my photos.

Early method of getting the right exposure

The differing albedo of my beanbag panels made it very difficult in my earlier photos to find an optimal exposure that did not blow out the white and light beige panels or under-expose the dark panels. For my original nine designs I did not have a technique for this. I had to use trial and error.

In the end, I combined the two exposures I had captured of most of my photos to produce the images in this guide. In each exposure I carved out by hand each panel I wanted using Photoshop's eraser tool with feathered edges. I then overlayed those layers onto the base layer. The feathered edges allowed the overlayed panels to blend with the base layer. With each color or set of colors in a separate layer in Photoshop, I could apply Levels and Color Balance layers to them individually, plus a Hue/Saturation layer to the entire image, so that the colors and exposure looked good for all the panels. That in combination with an Unsharp Mask filter resulted in much more presentable photos.

I did fairly minimal edits at first, but after proof-reading the second edition document prior to submission, I decided to do the thorough edit of all the photos. That took several days. Following is a comparison of three versions of my first 32-Panel ball photo.

Unedited original (higher exposure version)

Initial, basic edit using only the higher exposure version and no layers

Final edit – brought out the colors and corduroy texture much better

Improved HDR technique

For my 26-panel beanbag, which I developed several months after publishing the second edition, I improved my technique of capturing high dynamic range photos of the beanbags. My black, white, and red Rhombicuboctahedral beanbag has both extremes of albedo, as well as the red in the middle. So for my photos of it I captured four or five different exposures of the two angles I wanted so as to be sure I had a good exposure of each panel color, and then selected three of them to use. I extracted and individually edited the appropriate panels from each photo to produce the final image.

The montage on the next page shows the process.

Creating HDR Photos by Combining Elements from Multiple Exposures

Low exposure (1/40sec) to capture the white panels. The black panel details are lost at this exposure. I used this as a base layer. I erased the background with a feathered eraser brush and overlayed the other layers onto it.

Slightly higher exposure (1/30sec) to capture the red panels.

High exposure (1/6sec) to capture the black panels. White panels are blown out, red panels are over-exposed.

I extracted the panels by erasing everything around them using a small (10 - 30px) feathered eraser brush and working highly zoomed in (these images are 1,861px wide).

Preliminary HDR image
Red and Black panel layers overlayed onto the Low Exposure base layer.

Final HDR image
A separate Levels layer applied to each photo layer, and a Color Balance and Hue/Saturation layer applied to the entire image. Then an Unsharp Mask filter to sharpen the image.

APPENDIX IV – JUGGLING BEANBAG AND FOOTBAG MANUFACTURERS

Following are the juggling beanbag and footbag manufacturers whose websites were useful to me in finding design inspiration, researching for this guide, and obtaining example photos. I include them because they may be useful to my readers, and to help make these manufacturers known. I have not used any product made by these manufacturers, so I cannot personally recommend them. The list is in alphabetical order. For shops that do not sell footbags, the links point directly to the juggling beanbag products.

- **Adventure Trading:** http://www.adventuretrading.com/footbags/index.html
- **Bomb Footbags:** https://bombfootbags.com/
- **Dubé Juggling Equipment:** https://www.dube.com/beanbag/juggling-beanbags.php
- **EmCouros Slow Leather Atelier Juggling Balls & Games:** https://www.etsy.com/shop/EmCouros
- **Flying Clipper:** https://www.flyingclipper.com/
- **Footbag Central:** http://www.footbagcentral.com/
- **Footbag Shop:** https://footbagshop.com/
- **The Gballz Factory:** https://gballz.com/
- **Hane Dane Footbags:** https://hanedanefootbags.com/ *(no longer exists, but photos are available at https://www.facebook.com/profile.php?id=100054375258284)*
- **HaniaBAG – Handsewn 32-panel pro footbags:** https://www.haniabag.com/
- **Higgins Brothers:** https://higginsbrothers.com/en/
- **Oddballs:** https://www.oddballs.co.uk
- **Renegade Juggling:** https://www.renegadejuggling.com/juggling-balls/beanbags-mmx-leatherballs/
- **World Footbag:** http://worldfootbag.com/