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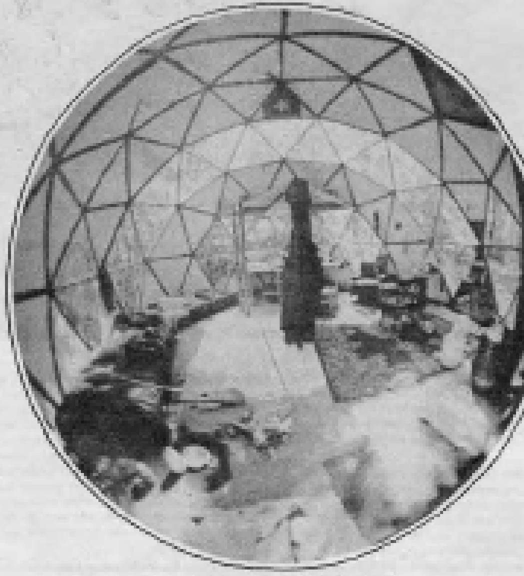


DOMEBOOK 2

published by Pacific Domes
a nonprofit educational corporation
price $4

also available by mail for $4
plus 25¢ postage. Add 20¢ tax
if you are a California resident.

Pacific Domes
Box 279
Bolinas CA 94924

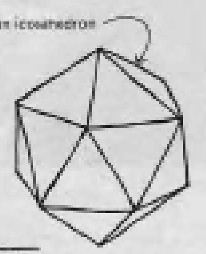
Distributed by Random House and in
Canada by Random House of Canada.

1st printing May 1971 - 20,000
2nd printing August 1971 - 40,000

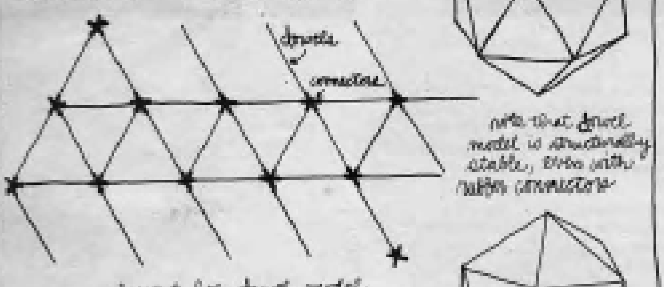
SIMPLE GEODESICS

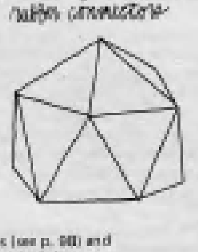
Geodesic domes are the invention of R. Buckminster Fuller. Domes can be generated from many different shapes; the ones we've built so far are derived from an icosahedron. To see how this works, take 20 equilateral triangles:

join them together, five triangles around each vertex to make an icosahedron (vertex is where triangle tips meet).



If you make this with dowels and rubber connectors, here is how to lay out connectors before joining all together

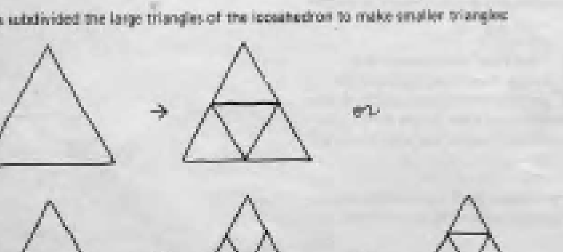




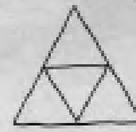
You can make a structure by removing the bottom five triangles (see p. 98) and placing it on the ground. It sits flat. When you remove the triangles it becomes unstable, but once the structure is connected to the earth it is again solid.

You can make small structures of icosahedrons, but if you begin to make larger structures, the fifteen triangles get large, heavy and you begin to need big timbers for struts.

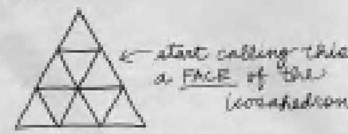
Fuller has subdivided the large triangles of the icosahedron to make smaller triangles



Two subdivisions along each edge means this is two frequency

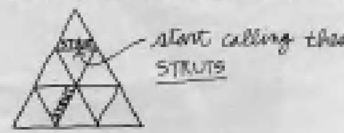


three subdivisions—three frequency, etc.

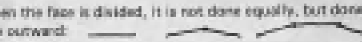


We'll use 3 frequency as an example, since it's a good frequency for 24-39' domes.

All faces of the spherical icosahedron are equal; thus, if we know the measurements of edge members of one face, we can make a sphere by repeating the pattern 20 times.



And when the face is divided, it is not done equally, but done so that the faces begin to curve outward:



This gives you more strength; the more subdivisions of one face of a given diameter icosa, the more numerous and smaller are the triangles, and the closer you get to a sphere.

Geodesics here gives you a set of constants for each strut length so that using these constants, and some multiplication, you can calculate any diameter sphere.

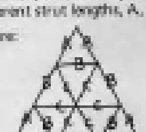
The constants are called **chord factors**.

◆◆◆◆◆◆◆◆◆◆◆◆◆ CHORD FACTORS ◆◆◆◆◆◆◆◆◆◆◆◆◆

A chord factor is a pure number which, when multiplied by a radius, gives a strut length. There are three different strut lengths, A, B, C.

The chord factors for this dome are:

A	.3486
B	.4035
C	.4124



Chord factor times desired radius equals strut length (in some unit of measure). If you want to get the strut length in inches, use inches of radius. For a 24' diameter dome,

Radius is 12'. Convert to inches: 144"

A.	B.	C.
.3486	.4035	.4124
144	144	144
13944	16140	16496
13944	16140	16496
3486	4035	4124
50.1984	58.1040	59.3856

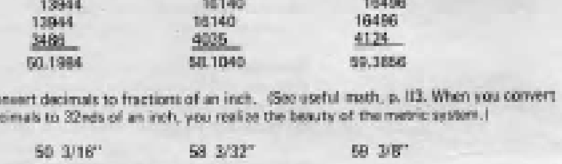
Convert decimals to fractions of an inch. (See useful math, p. 113. When you convert decimals to 32nds of an inch, you realize the beauty of the metric system.)

50 3/16" 58 3/32" 59 3/8"

These are strut lengths for a 24' diameter sphere.

If you use hubs, you must subtract for the diameter of the hub.

If you make the model of a three frequency sphere (See p. 6), you will discover that it can be cut off in three ways, depending upon its orientation in space:



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We have just partially explained a geodesic dome that is

Three frequency

Class One (Alternate)

and generated from an **icosahedron**.

Geodesic domes can be of different frequencies, other breakdowns, and can be generated from other shapes, such as the octahedron or tetrahedron. They can also produce other-than-dome shapes.

MODELS

Making Model Spheres

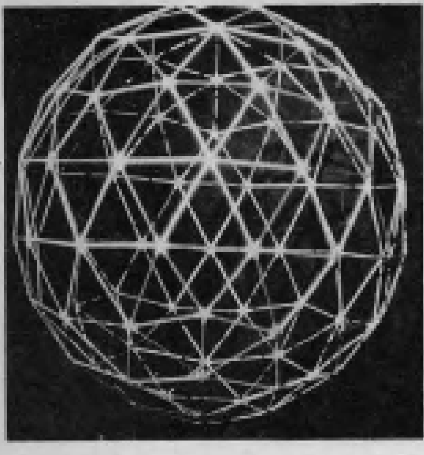
A dome is a portion of a sphere. If you make a sphere model you can see where to cut it off to make a dome, how to orient it to the earth, and trip out on the different patterns.

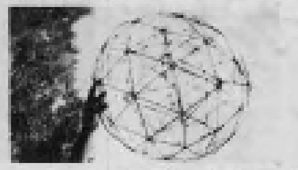
Here are instructions for two types of geodesic sphere models: the *alternate* and the *triacon*. Both models are the same diameter and can be studied with respect to making full scale domes.

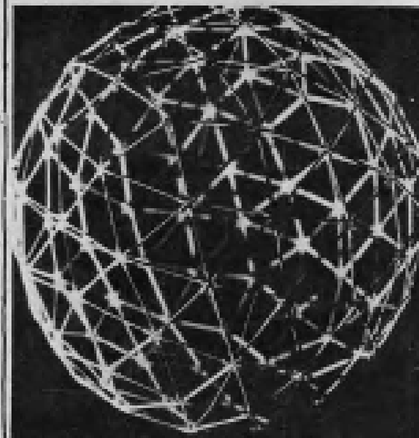
For each model, we give calculations for the strut lengths. It would be a good thing if you checked these out for yourself before cutting dowels; to do this you get chord factors for the *alternate* on p. 109 and for triacon on p. 110.

Multiply the chord factor times the desired radius in inches to get the chord length; then—important—subtract the length of the connector, which is 3/8" for rubber connectors, to get strut length.

The principle above is the same for any dome made with vertex connectors. In the following tables we have subtracted the 3/8".







3-FREQUENCY ALTERNATE 2 FT DIAMETER SPHERE

Strut	Chord Factor	Strut Length *	Color Code	Make This Many
A	.3486	3 13/16"	Red	60
B	.4035	4 15/32"	Blue	90
C	.4124	4 9/16"	Yellow	120

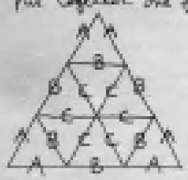
*We have subtracted 3/8" (.375) for connector

Example: .3486
X12"(radius)
6972
3486
41832

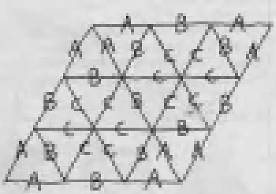
4183
-.375
3808 = 3 13/16"

Putting Together Alternate Sphere:

Put together one face:



Then add another:



and continue until you have 20 of these subdivided triangles, making a sphere.

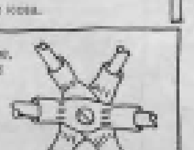
The colored struts will show you what's going on:
—red: spokes into center of each pentagon
—blue: outlines both hexagons and pentagons
—yellow: spokes into hexagon centers

To compare the sphere with the icosahedron from which it originated you can suspend an icosa inside, using 5" long uncolored struts through the center of the red struts to the vertices of the icosa.

To make different domes, you can remove struts, or while sphere is hanging try different orientations, and run a string around where you want to cut it off. Hanging from pentagon center, you can cut it off at 3/8 or 5/8. Hanging from blue strut (one of those in between hexagons) you can cut it in half—a hemisphere, in which case you will be cutting some triangles in half.

The 12 pentagon centers in the sphere are the 12 vertices of the icosa.

Another type connector is to take pieces of flexible clear vinyl tube, cut in sections, shove dowels in, then put a screw with washers and bolt through the tube.



You get tubing that fits tightly over the dowel. This can be used for bigger than 1/8" dowels, and makes handsome hubs.

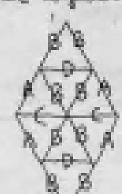
4-FREQUENCY TRIACON 2 FT DIAMETER SPHERE

Strut	Chord Factor	Strut Length *	Color Code	Make This Many
A	.3134	3 3/8"	Green	60
B	.3361	3 21/32"	Red	180
C	.3628	3 31/32"	Yellow	60
D	.3894	4 5/16"	Blue	60

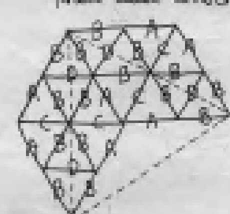
*See left

Putting Together Triacon Sphere:

Put together one diamond:



Then add another:



and continue until you have 30 of these subdivided diamonds. Dotted lines are face of icosa. 4 divisions along this line = 4 frequency

Notice the pentagonal flower shape when you have the first ten diamonds together.

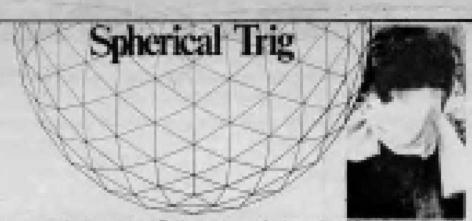
The triacon sphere is not as easy to divide into a dome as the alternate, where continuous lines running through the sphere suggest cut-off points. If you suspend the model from different points, you will see different cut-off possibilities, all necessitating truncation of triangles to get the dome to sit flat. With the Aluminum Triacon dome (p. 26) we made a hemisphere truncation.

I was tempted to make a partial dome of ten diamonds, resting the bottom five points on posts maybe 8' high, with clear plastic or glass across the bottom, giving the dome a floating look.

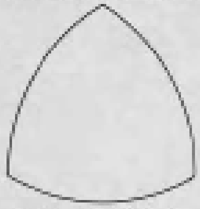
The lines of the alternate are simpler than the triacon. An advantage we found in the triacon is that triangles have a lower altitude; with a 24' diameter you can cut triacon triangles out of a 4' width, but not alternate triangles. You can figure the maximum diameter for a 4-frequency triacon dome, still being able to cut triangles out of standard 4' width material.

These two models are useful geometries for home domes, 26-40' diameters.

Spherical Trig

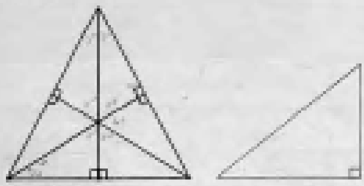


Spherical trigonometry is the method Fuller uses to calculate chord factors and angles. Spherical trigonometry is about spherical triangles—triangles made up of arcs on the surface of a sphere. Because of the curvature of the sphere (positive curvature), the angles of a spherical triangle will add up to more than 180°. The amount over 180° is called the spherical excess. The sum of the angles will also be less than 540°, because a spherical triangle has to have 3 separate arcs, so where the arcs intersect (the vertices) the angle will be less than 180°.

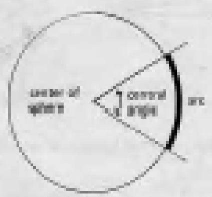


Equilateral spherical triangle.

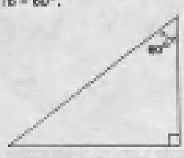
You calculate within a spherical right triangle. One of the 6 identical right triangles formed by the 15 great circles.



Degrees are used to measure the arcs too: the arcs are measured by their central angle.



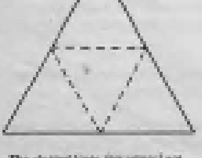
The angle made by the arcs that intersect at the center of a face will be 60°, because there are 6 angles there and they're all equal, and the angles around any point on a sphere equals 360°, so 360°/6 = 60°.



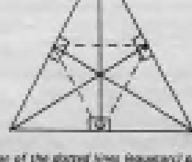
The angles of the right triangles formed at the vertices of the face are 36°; the spherical icosa has 5 faces at each vertex so 360/5 = 72° and the lines from the center of the face to the vertex bisect the 72° angle, 72°/2 = 36°.

A great circle that bisects the edges of a spherical polyhedron is called an equator. An equator crosses the faces of a polyhedron equally. A great circle that bisects the edges of a spherical polyhedron and crosses the faces of the polyhedron equally is called an equator. The 6 and 10 great circles are equators.

Each of the 6 great circles crosses 10 of the icosahedron's faces; 360° (in a complete great circle)/10 = 36°. The right triangles cut the 1/10 of the equator in half.

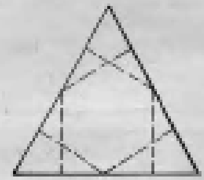


The dotted lines (equators) are 1/10 the whole equator.



The section of the dotted lines (equator) passing through a right triangle is 1/20 of the whole equator.

Each of the 10 great circles crosses 12 of the icosahedron faces; 360°/12 = 30°.



Each dotted line (from edge to edge) is 1/12 of the whole equator.

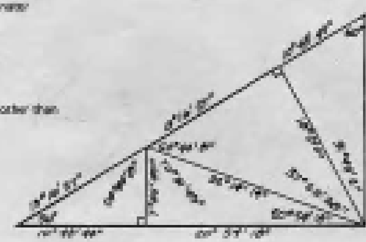
By more calculations (using spherical trig) you get the data for the 31 great circles. From that data you can get information for any frequency.

BASIC DATA 31 GREAT CIRCLES

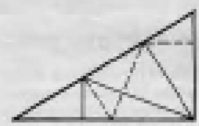
In lowest common denominator of a sphere's surface

2 different external edges
3 different internal edges

6 different internal angles other than 90° or 60°

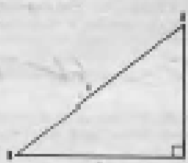


solid lines 31 great circles,
dotted lines superimposed
Fuller 4_v alternate.
See Clinton's Class I, Method 3



The other variables can be calculated because any 2 variables will determine a right triangle, which has a right angle and 5 variables.

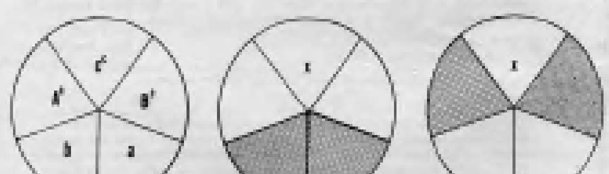
To identify sides and angles:



C is always the right angle,
A and B can be interchanged.

To solve a right spherical triangle, Napier's rules are used.
Rule 1: the sine (of any part) = product of cosine of the opposite parts
Rule 2: the sine (of any part) = product of tangents of the adjacent parts
When using Napier's rules you use logarithms. Adding logarithms is the same as multiplying.

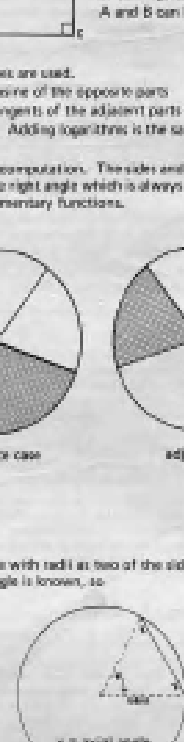
The triangle can be put into an easy form for computation. The sides and angles are related in the same way as in the triangle. The right angle which is always the same can be omitted. The small c means to use complementary functions.



Chord factor = 2 times the sine of $\frac{angle}{2}$.

For axial angles, construct an isosceles triangle with radii as two of the sides, and the chord in between as the third. The central angle is known, so

$$\frac{180^\circ - \text{central angle}}{2} = \text{axial angle.}$$



For planar face angles: Find the spherical excess for the whole triangle (all the angles 180°), divide by three, then subtract the result from every vertex.

GEODESIC GEOMETRY

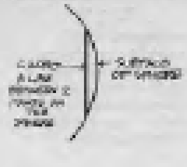
Jonathon Kanter

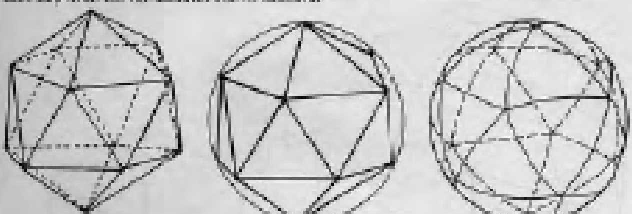
A dome is a multifaceted polyhedron in which all the vertices lie on the surface of a sphere. Domes are developed from the tetrahedron, octahedron and icosahedron. Domes have the symmetry of the tetrahedron, octahedron and icosahedron, and also of their duals in the relevant breakdown.

The sphere encloses the most volume with the least surface, and is the strongest shape against internal and radial pressure.

The Platonic solids are the best shapes to start from because they have the most symmetry and regularity. A structure composed of triangles is best because a triangle is the simplest subdivision of a surface, and the only stable polygon with flexible connections. Domes could also be developed from semi-regular or other shapes. Domes can also be produced to form any other besides spherical shapes (see Elliptical Domes).

What follows explains domes developed from the icosahedron. The icosahedron is used because, of the Platonic solids with triangular faces (the tetrahedron, octahedron, and icosahedron) it most closely approximates the sphere. Domes can be developed in the same way from the tetrahedron and octahedron.

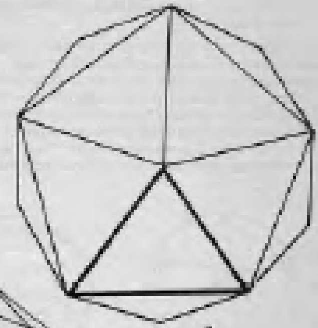




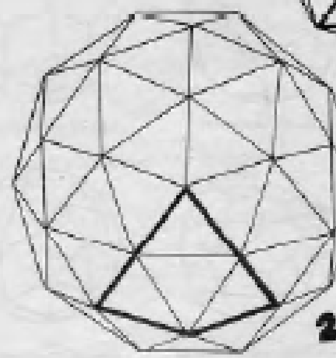
ICOSAHEDRON — ICOSAHEDRON WITHIN SPHERE, ALL VERTICES TOUCH SPHERE — ICOSAHEDRON PROJECTED ONTO SPHERE

Two breakdowns are possible when the face is subdivided into triangles and the symmetry of the equilateral triangle face is retained. They are the alternate and triacon. This is a general geometrical explanation.

There are different sets of chord factors within the basic geometry. Clinton derives his from the coordinates of vertices on the sphere and use analytical geometry. See Geodesic Math, p. 108 and Chord Factors, P. 108. Fuller derives his by spherical trig. calculations using arcs on a sphere, see Spherical Trig and 31 Great Circles. Fuller develops domes by projecting the icosahedron onto the sphere and then dividing the face of the spherical icosahedron with great circle arcs on the surface of the sphere. (a great circle arc cuts a sphere in half, it is the shortest distance between two points on the surface of a sphere) except for some arcs in the Alternate truncatable (Clinton's Class I method 4).

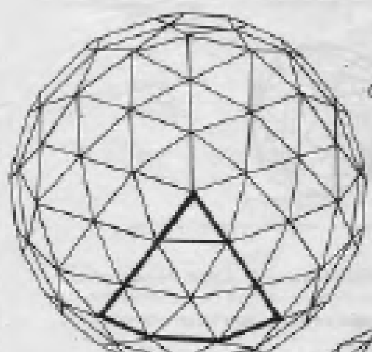


1v

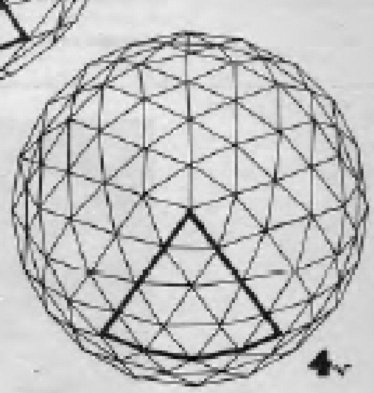


2v

ALTERNATE
BREAKDOWN
• RIGHT SIDE UP •
ONE ICOSA FACE IS OUTLINED



3v

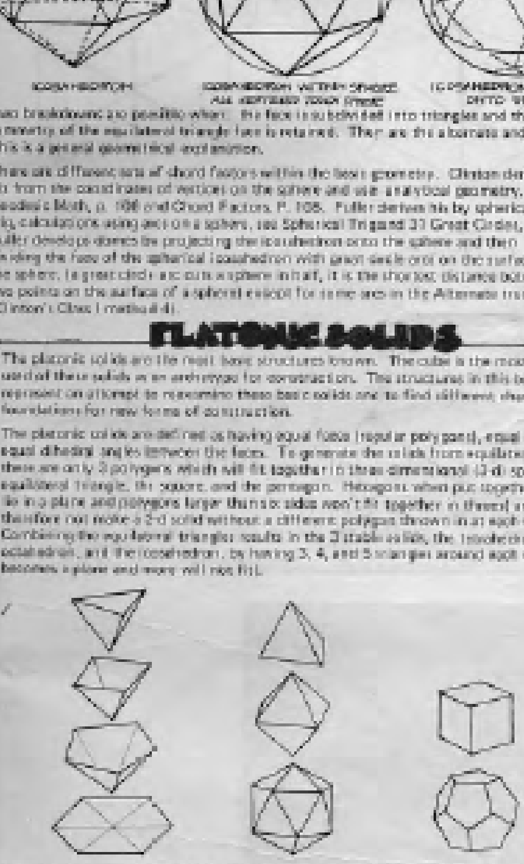


4v

PLATONIC SOLIDS

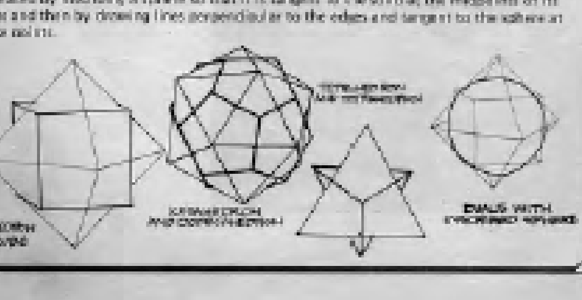
The platonic solids are the most basic structures known. The cube is the most commonly used of these solids as an archetype for construction. The structures in this book represent an attempt to reexamine these basic solids and to find different channels and foundations for new forms of construction.

The platonic solids are defined as having equal faces (regular polygons), equal vertices, and equal dihedral angles between the faces. To generate the solids from equilateral polygons there are only 3 polygons which will fit together in three dimensional (3-d) space: the equilateral triangle, the square, and the pentagon. Hexagons when put together in threes lie in a plane and polygons larger than six sides won't fit together in threes and will therefore not make a 3-d solid without a different polygon thrown in at each vertex. Combining the equilateral triangles results in the 3 stable solids, the tetrahedron, the octahedron, and the icosahedron, by having 3, 4, and 5 triangles around each vertex (6 becomes a plane and more will not fit).

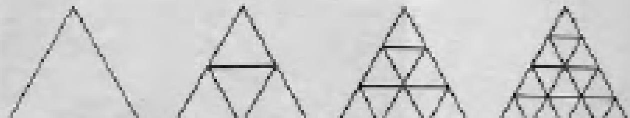


Squares and pentagons will fit together in threes at each vertex: this produces the cube and the dodecahedron.

Two solids are considered to be duals if the number of vertices of one equals the number of faces of the other and they have an equal number of edges. The dual of a solid can be generated by inscribing a sphere so that it is tangent to the solid at the midpoints of its edges and then by drawing lines perpendicular to the edges and tangent to the sphere at those points.



For any breakdown, as the frequency increases the number of chords and the number of facets increases so the dome becomes more spherical. Frequency is the same as the number of divisions of the edge.



1 FREQUENCY 1v — 2v — 3v — 4v

The face is divided by lines (arcs on a sphere) parallel to each edge. The lines go from edge to edge.

All repeating patterns in alternate can be shown in one face (△). Henceforth, v = frequency

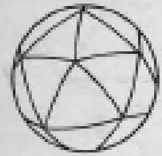
GEODESIC GEOMETRY

TRIACON

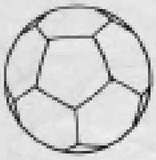
BREAKDOWN
· VERTEX UP ·

The 2v triacon is produced by the combination of the dodecahedron, and triacontahedron. See 31 Great Circles.

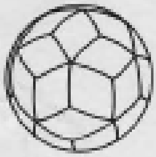
The edge of the icosahedron is not part of the dome in the triacon breakdown. The divisions are made perpendicular to an edge. The triacon only works on even frequencies because you must have the 2v subdivision from the middle of each edge to the opposite vertex. In diagrams the icosahedron edge is dotted. The triacon produces 6 identical right triangles for each icosahedron face. There are 120 of them in a complete sphere and they are the smallest identical subdivisions of a sphere surface. Besides the right triangles the triacon has 3 repeating patterns. The triacon can be viewed as a high frequency icosahedron, dodecahedron, and triacontahedron.



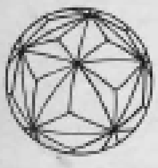
spherical icosahedron



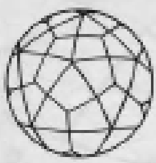
spherical dodecahedron



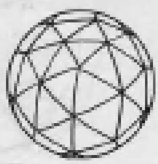
spherical triacontahedron



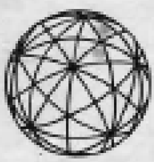
spherical icosahedron and triacontahedron combined



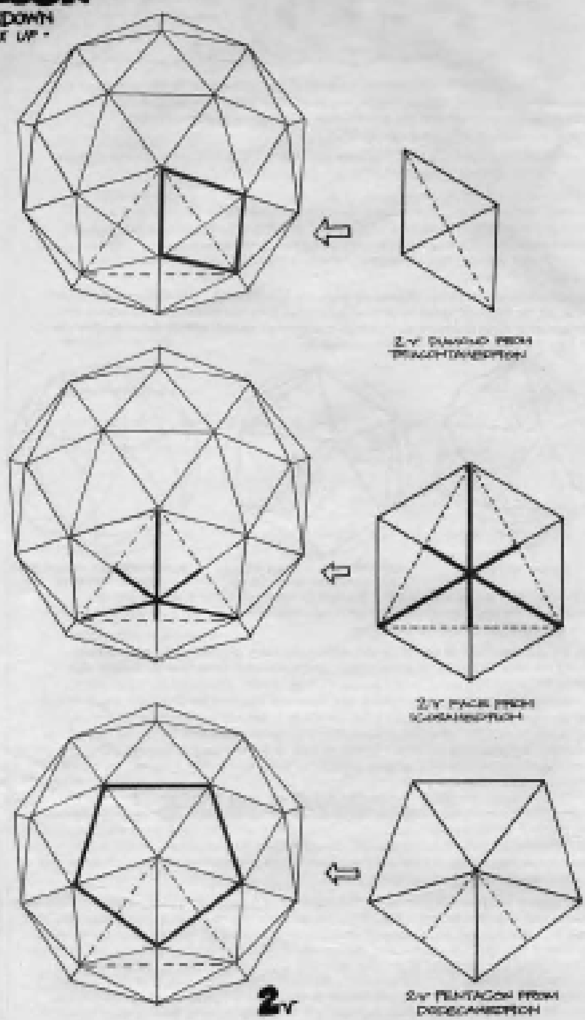
spherical icosahedron and dodecahedron combined



spherical dodecahedron and triacontahedron combined

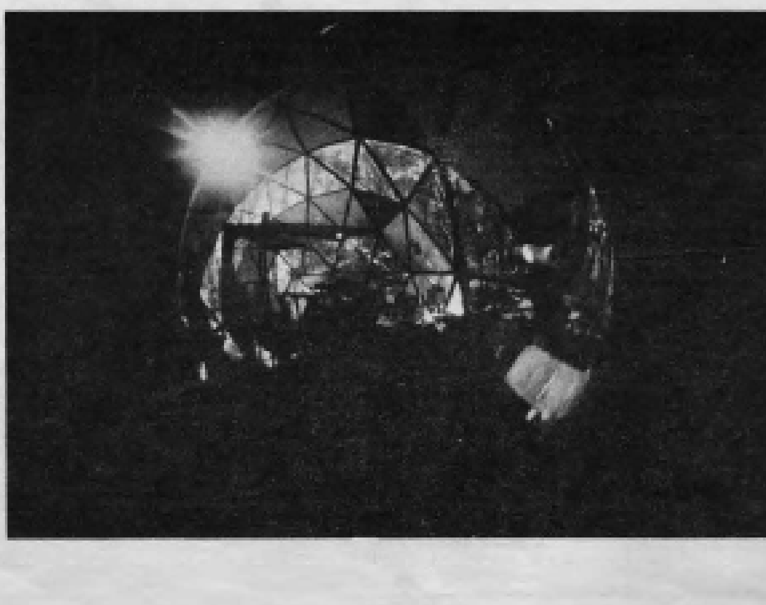


Spherical icosahedron, dodecahedron and triacontahedron combined.

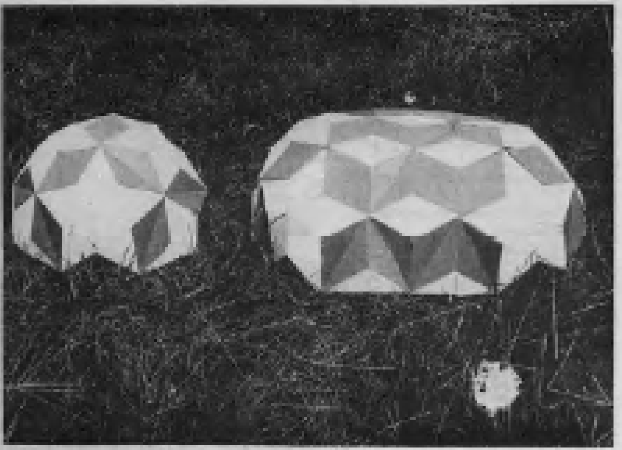


Every triacon breakdown has:

20 identical triangular faces, from the icosahedron
30 identical diamonds from the triacontahedron
12 identical pentagons from the dodecahedron.



-styrene sheets, clear rods: Cenetron Corp/P.O. Box 1952/Fresno, CA 93718
-colored rods (ruby, amethyst, robins' egg blue, etc.), double bubble solution—you can blow bubbles with this that last an hour, for photo and study purposes: Techno Scientific Supply/P.O. Box 191/Baldwin, N. Y. 11510
-Large amounts rubber connectors: Geodestix/Box 6179/Spokane, Washington 99206, although they have had some bad plastic lately, and the connectors tend to disintegrate in the sun.



MEMBRANE MODELS

paper models on page 123

These are models of the dome with skin on. This way you get an idea of interior qualities (by holding the model over your head), outward appearance, and where to put windows, doors, etc.

Use a good quality white cardboard. Use a compass to make templates (a template is a master pattern used to mark components).

Using template draw as many components as you need. Cut on a paper cutter if you have one, scissors if not. Put together with masking tape on the inside. Paint with acrylic polymer or white lacquer. Leave openings for doors, use clear plastic (Saran Wrap) for windows. Hold it over your head to see what it'll be like inside. Take it to the building site and watch the sun's pattern through the windows—this will help you in proper dome orientation.

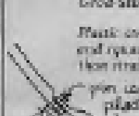
We made a beautiful model this way using chord factors from Fuller's patent on laminar geodesic domes (see p. 94), creasing diamonds inward along the long axis.

Other models:
-you can string straws together with sewing thread. Difficult, but it makes delicate models.
-hot melt glue is useful—it sets up in 30 seconds.

two letters on plastic straw struts:

Good kits are great for models, but they cost and you have to wait for them.

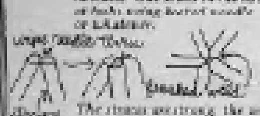
Plastic straws are cheaper and easier to come by. Dip the ends in hot water and squash them flat. Puncture them first with a pin (safety pin is handier than them straight). Fasten them with staples fastened by hand.



Yours
Stan Armstrong
Halifax, N.S. Canada

Also use a pin and small piece of rubber eraser.

This might be the world's cheapest way to model geodesics, zomes, etc.—buy a box of plastic soda straws, get a good fat candle and some big darning needles. Cut struts to [illegible] from the soda straws; "weld" them together at hubs using heated needle. You can [illegible] the needle with tape or whatever.



wipe needle through point where straws touch straws
finished weld

The straws are strong, the welds are stronger—no hubs needed, you get hundreds of struts for 39 cents (big boxes like restaurants use). Try different colors for strut coding, tissue paper [illegible] on for window and panel layouts—these models are so cheap and [illegible] you get into them right away and hang 'em up to watch your progress.

Thanks for Domebook One.

Bob Bridge
Henry Simons

Gary Bradbury
Gibsons, B. C. Canada

tetrahedral kites

I think Domebook II should include a page on recreation for the domeowner and some model building experience for the domebuilder: tetrahedral kites! They are the most stable highest flying kites around. Alexander Graham Bell built large man-carrying kites as well as more conventional Sunday afternoon types. They can come in as many sizes and materials as domes, except, perhaps, ferro concrete.

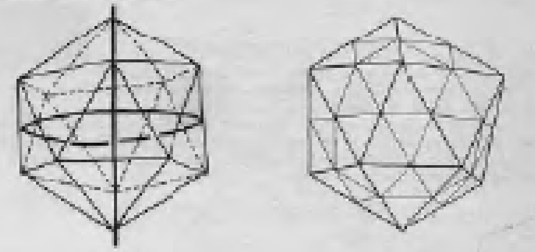
Simply take a tetrahedron, fill in two sides with paper or fabric, tie on a string and fly it. Higher frequencies mean more lift and stability. Bell's were so large they had to be towed by a speedboat to get up in the air, but they carried a passenger as well!

Yours truly
Robert W. Easton
Keene, New York

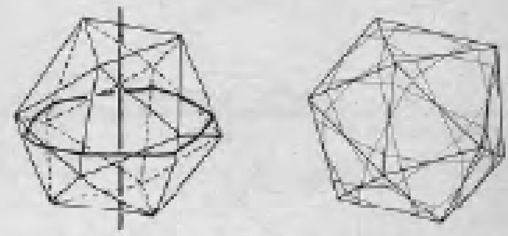
great circles

A plane that passes through the center of a sphere is called a *great circle plane*. A great circle cuts a sphere exactly in half.

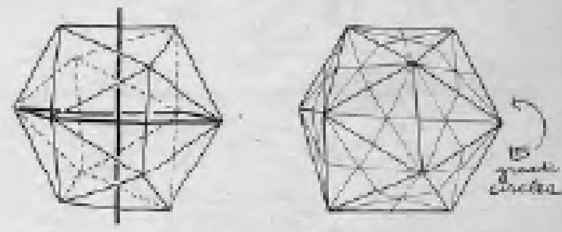
Fuller has discovered that there are 31 great circle planes produced by different rotations of the icosahedron:



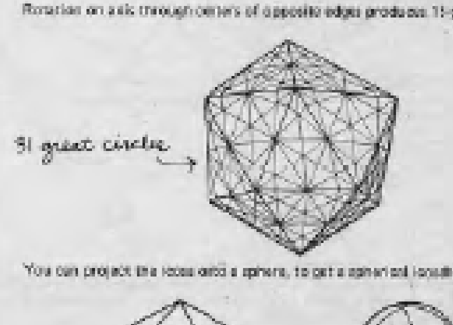
Rotation on axis through opposite vertexes produces six great circle planes.



Rotation on axis through centers of opposite faces produces ten great circle planes.



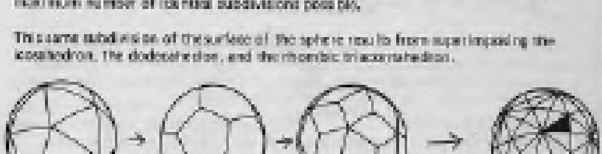
Rotation on axis through centers of opposite edges produces 15 great circle planes.



You can project the icosa onto a sphere, to get a spherical icosahedron:

The fifteen great circles divide the surface of the sphere into 120 identical triangles—the maximum number of identical subdivisions possible.

This same subdivision of the surface of the sphere results from superimposing the icosahedron, the dodecahedron, and the rhombic triacontahedron.



Rotating the spherical icosahedron about different axii results in a subdivision of the surface for which all line segments are portions of great circles and for which all great circles are completely represented.

In the tricon and alternate breakdowns, although all the chords are portions of great circles, not all of the great circles are completely represented.

For more on this type geometry see Popko's *Geodesics*. Fuller's math book, probably to be titled *Energetic-Synergetic Geometry* has been in process for many years; when it is published, it will clarify Fuller's math discoveries.