# DOMEBOOK
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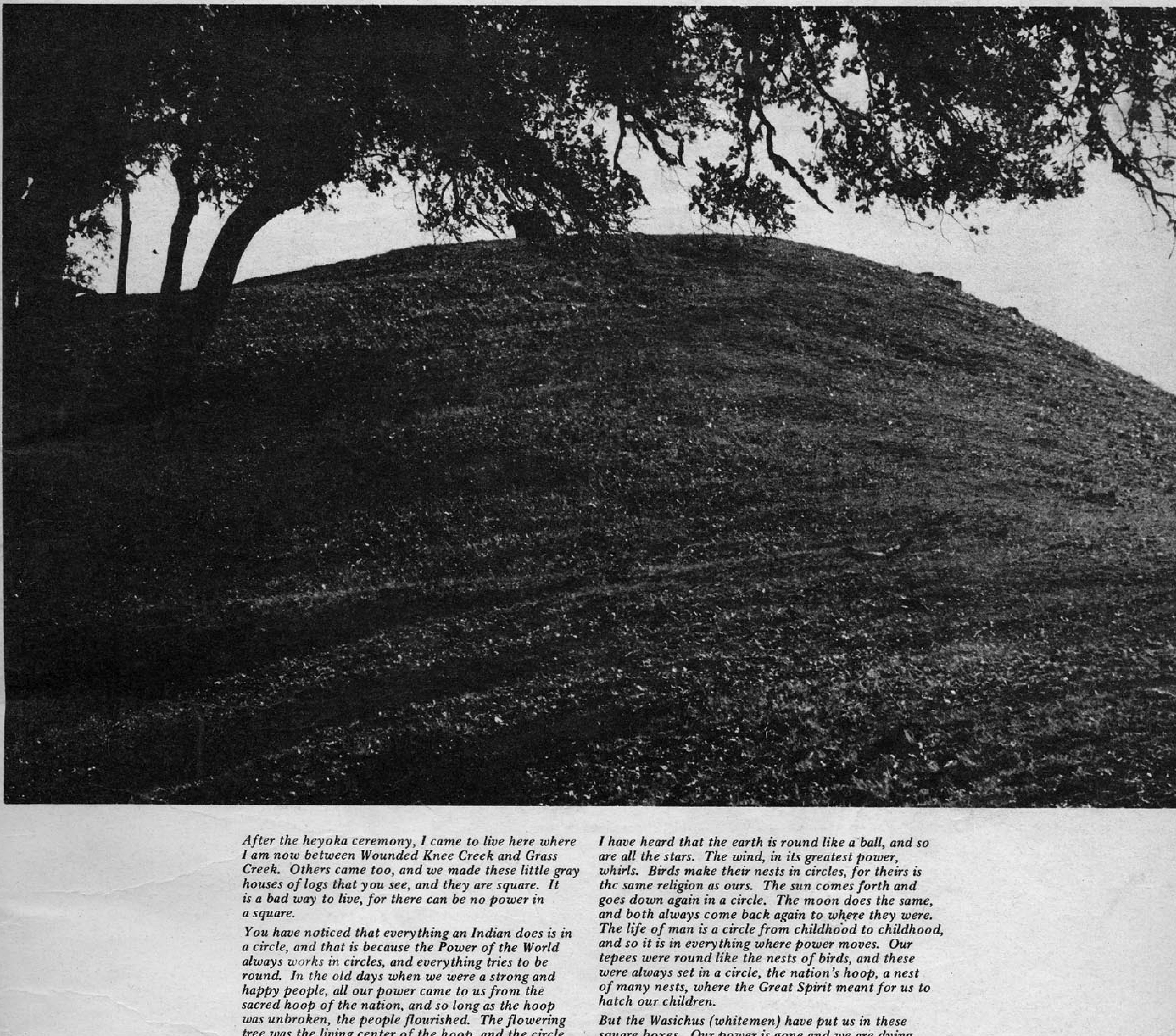

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*You have noticed that everything an Indian does is in a circle, and that is because the Power of the World always works in circles, and everything tries to be round. In the old days when we were a strong and happy people, all our power came to us from the sacred hoop of the nation, and so long as the hoop was unbroken, the people flourished. The flowering tree was the living center of the hoop, and the circle of four quarters nourished it. The east gave peace and light, the south gave warmth, the west gave rain, and the north with its cold and mighty wind gave strength and endurance. This knowledge came to us from the outer world with our religion. The sky is round, and I have heard that the earth is round like a ball, and so are all the stars. The wind, in its greatest power, whirls. Birds make their nests in circles, for theirs is thc same religion as ours. The sun comes forth and goes down again in a circle. The moon does the same, and both always come back again to where they were. The life of man is a circle from childhood to childhood, and so it is in everything where power moves. Our tepees were round like the nests of birds, and these were always set in a circle, the nation's hoop, a nest of many nests, where the Great Spirit meant for us to hatch our children.*

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*from Black Elk Speaks*

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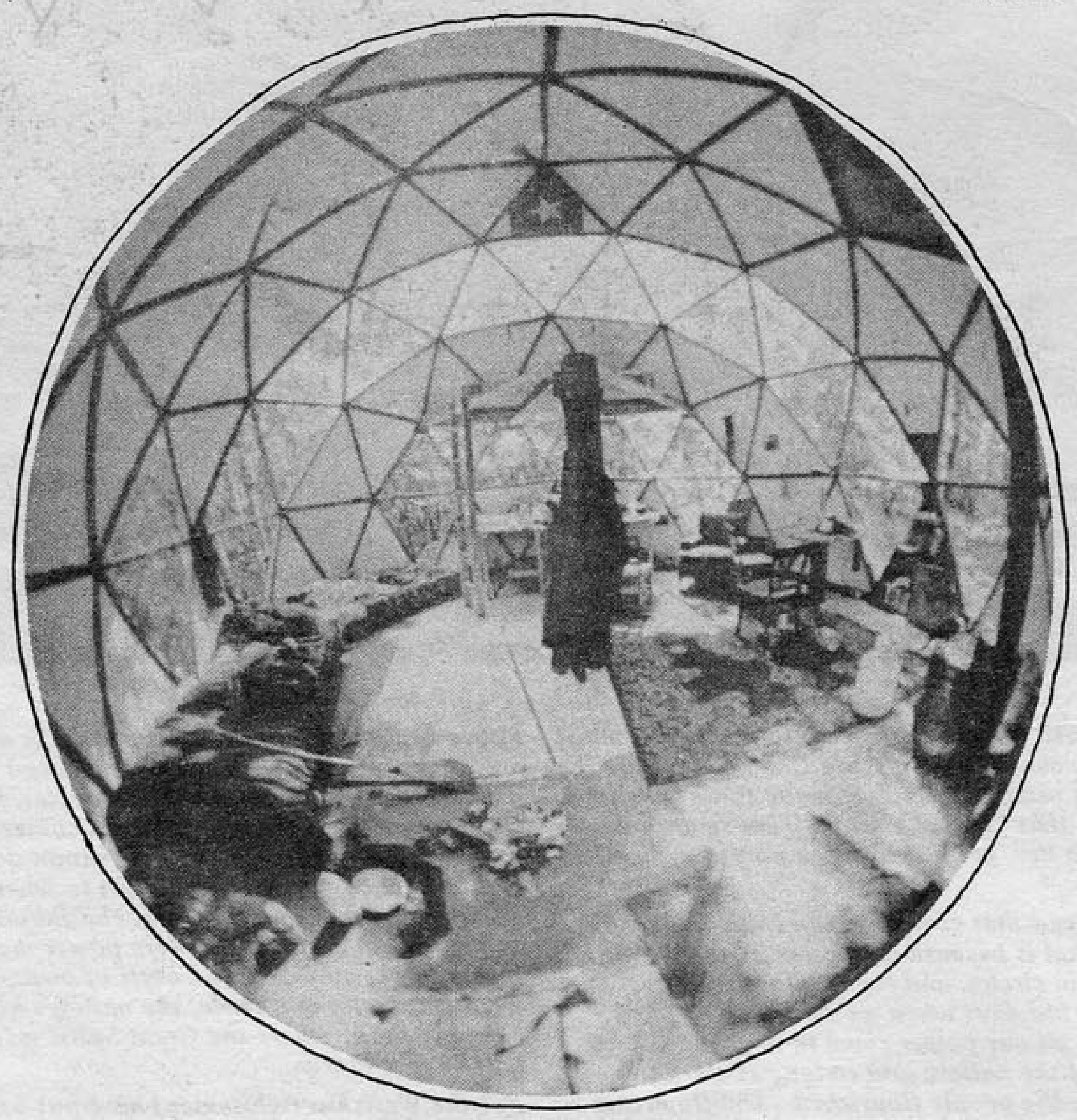

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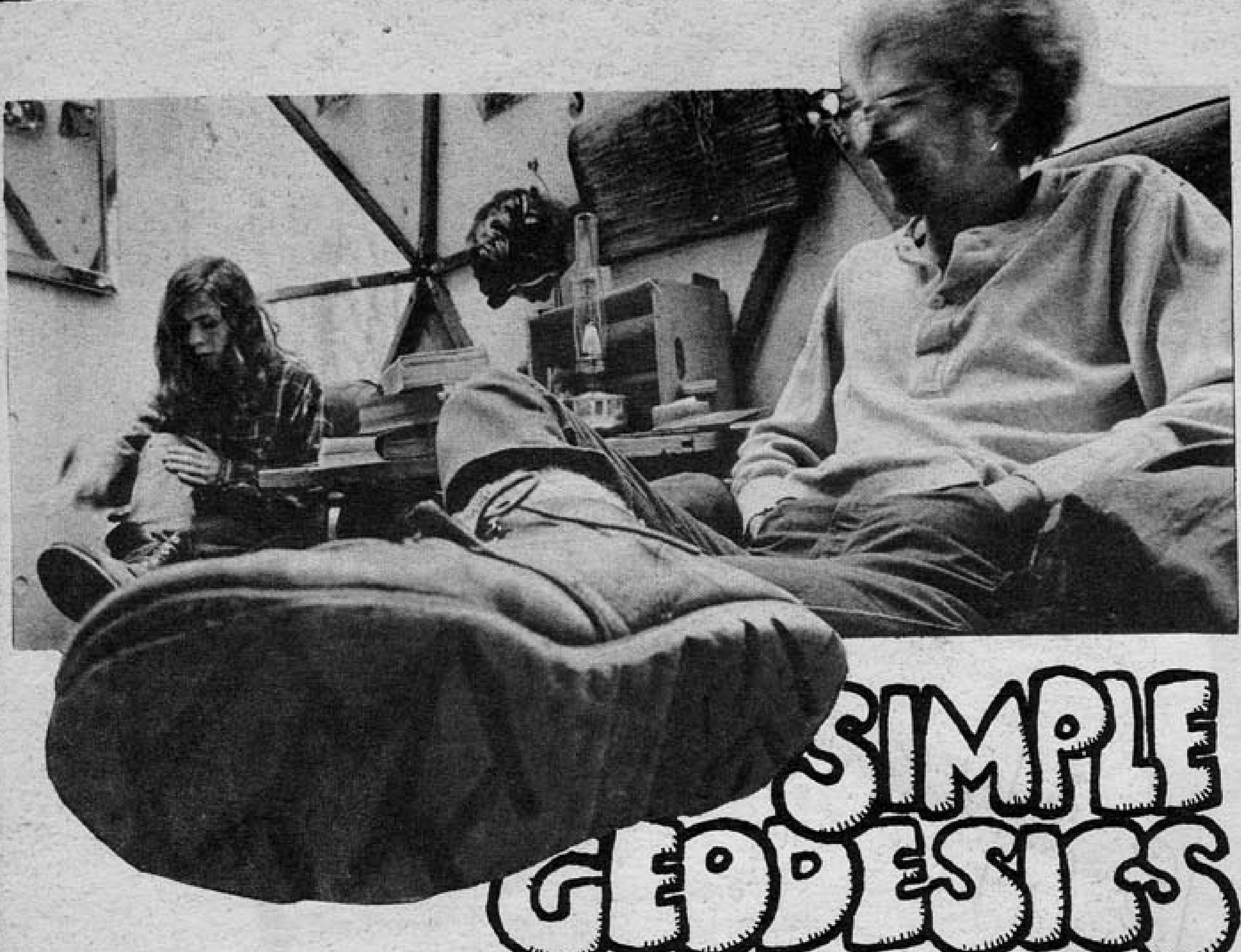


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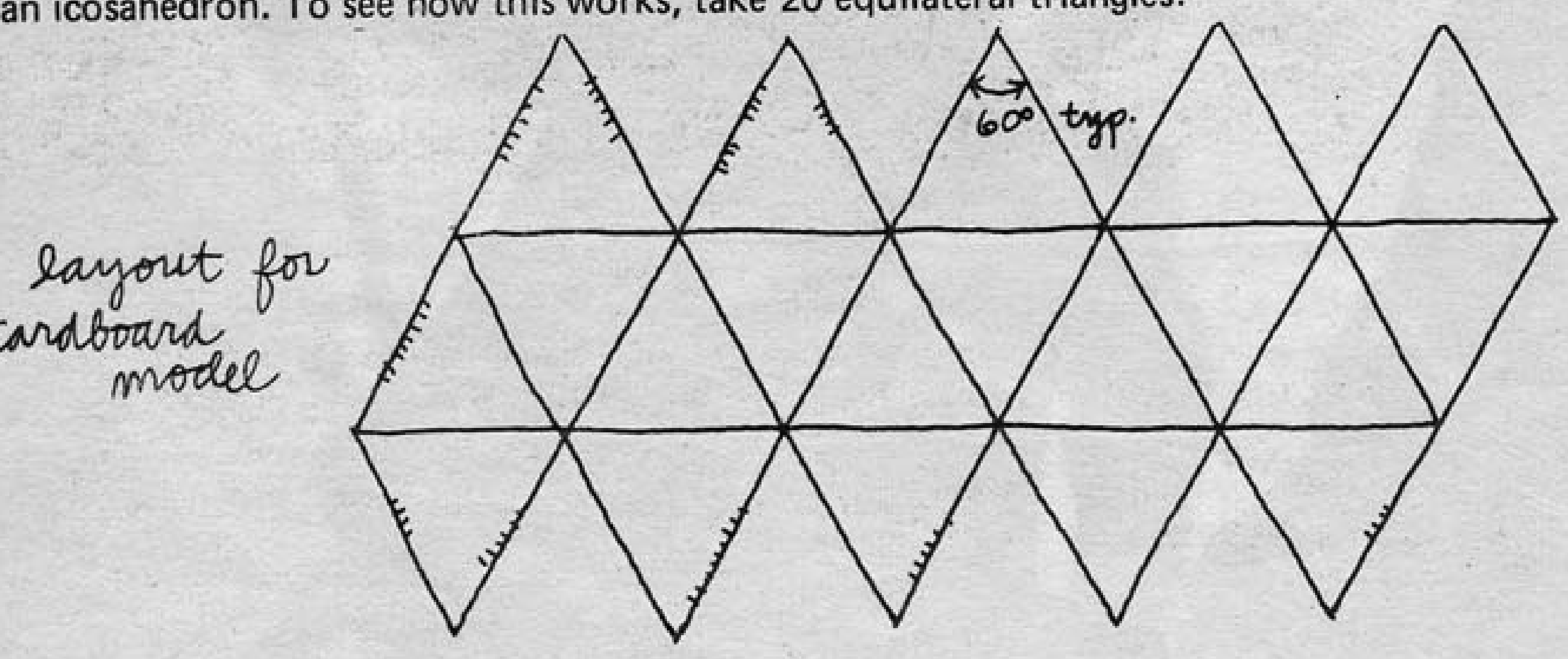


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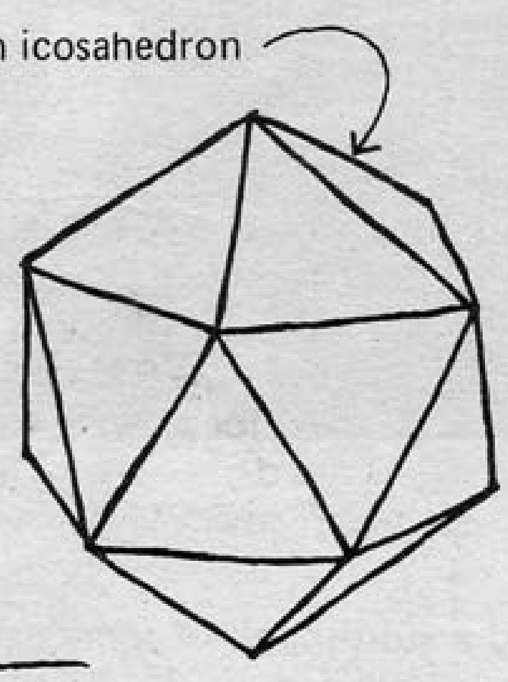

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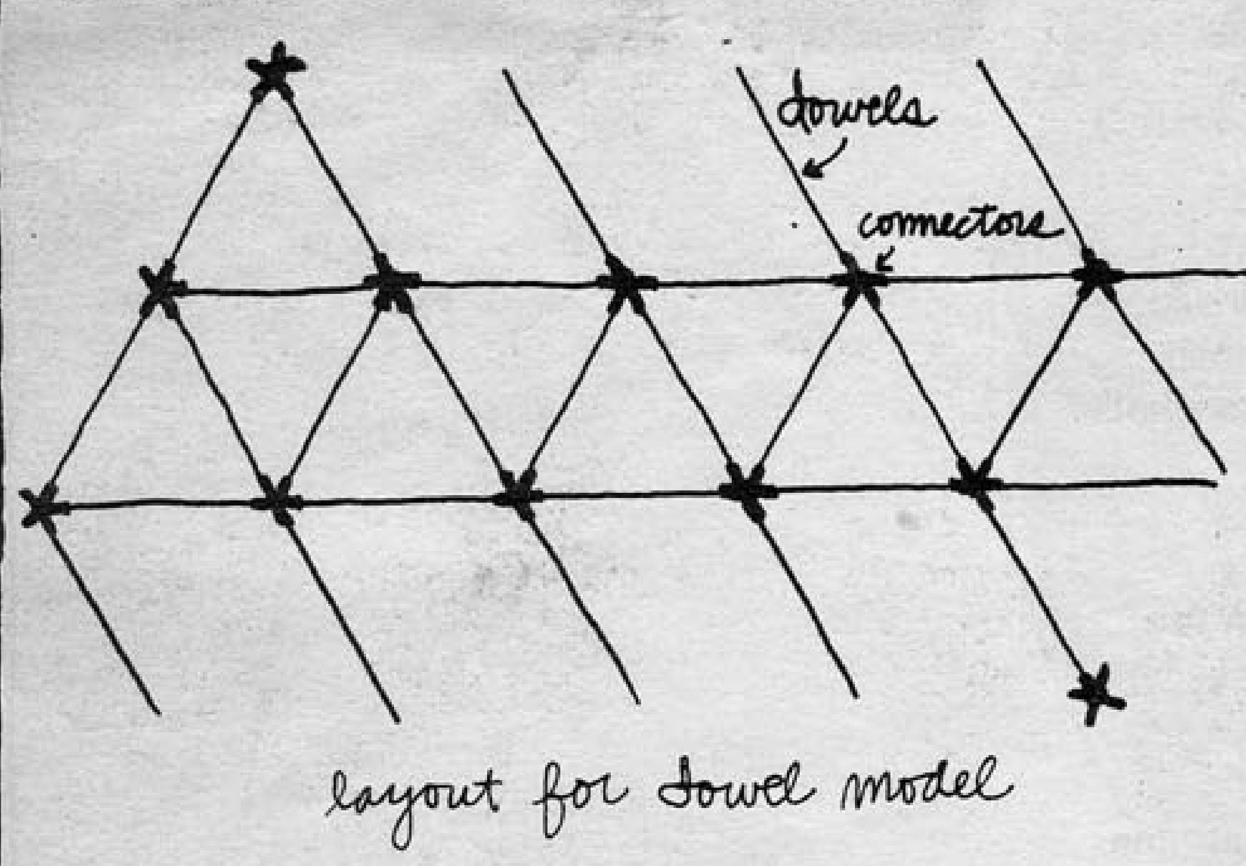


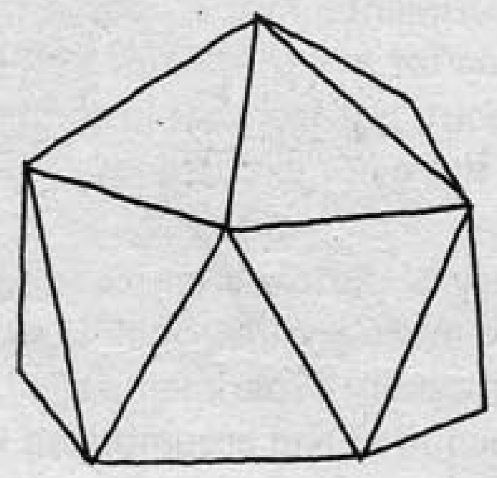

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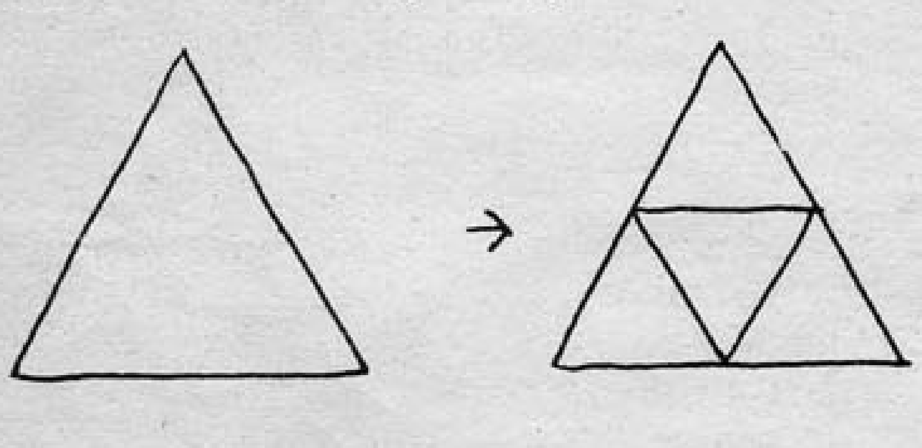


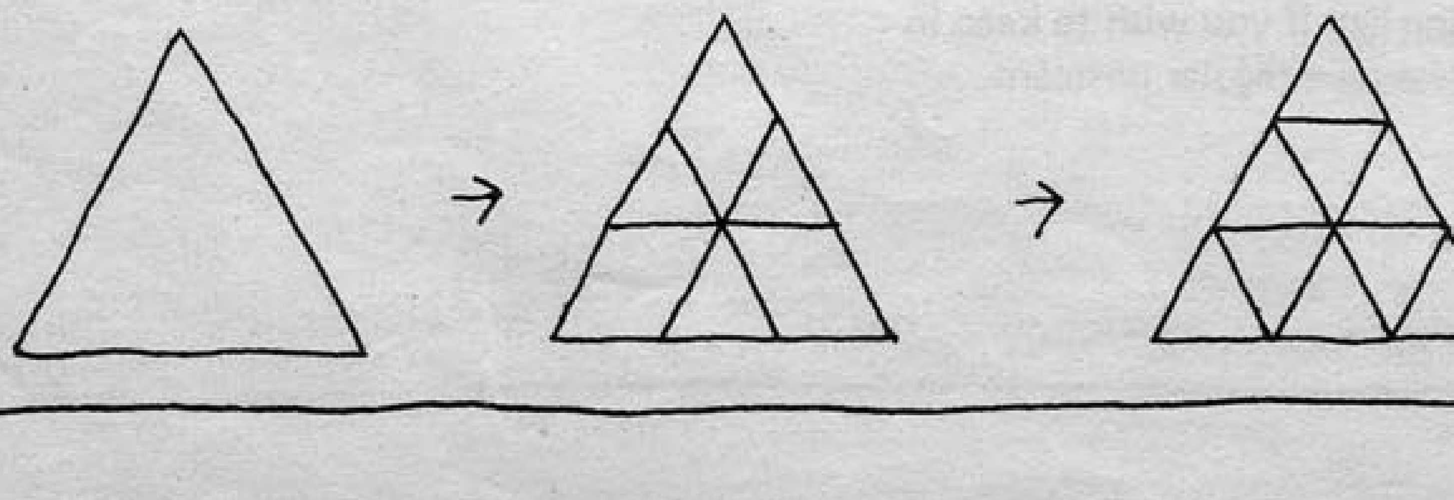



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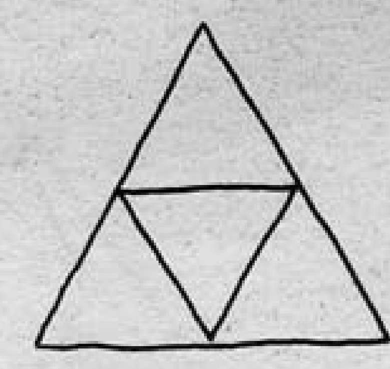

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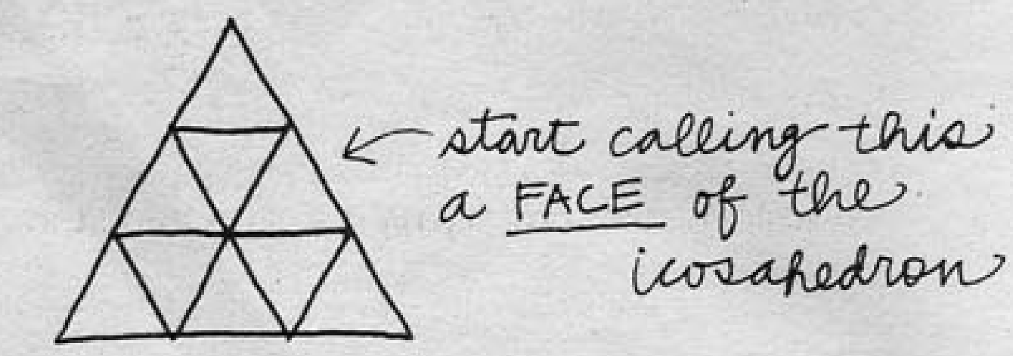


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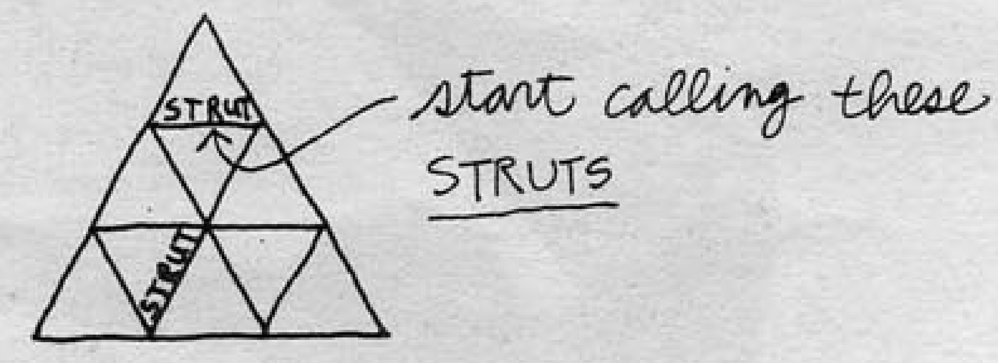
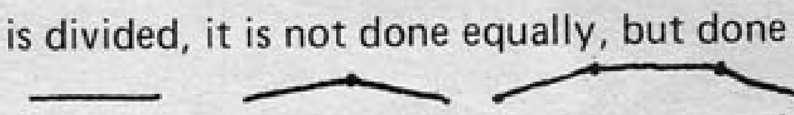



And when the face is divided, it is not done equally, but done so that the faces begin to curve outward: 

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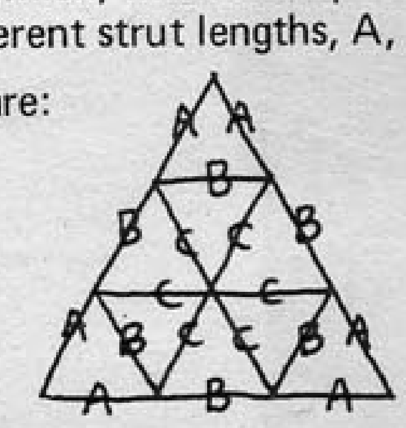


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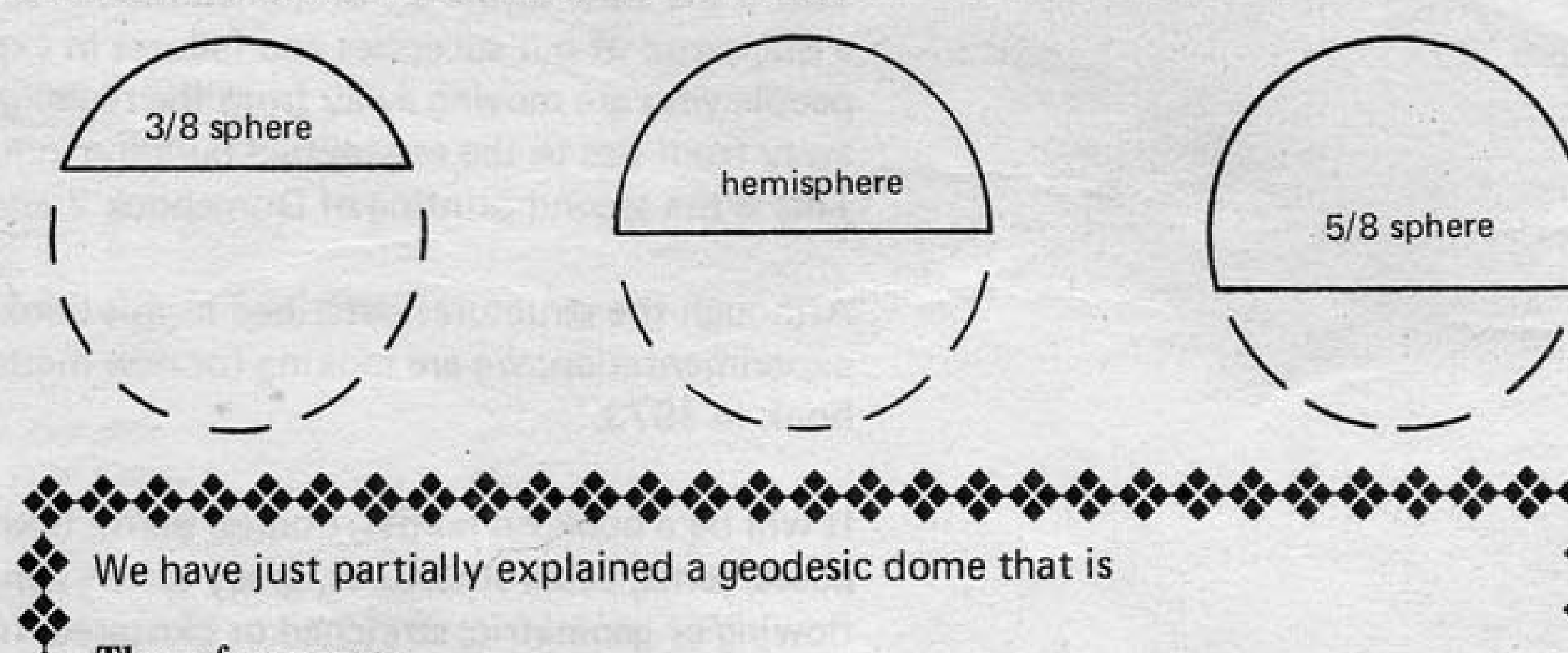


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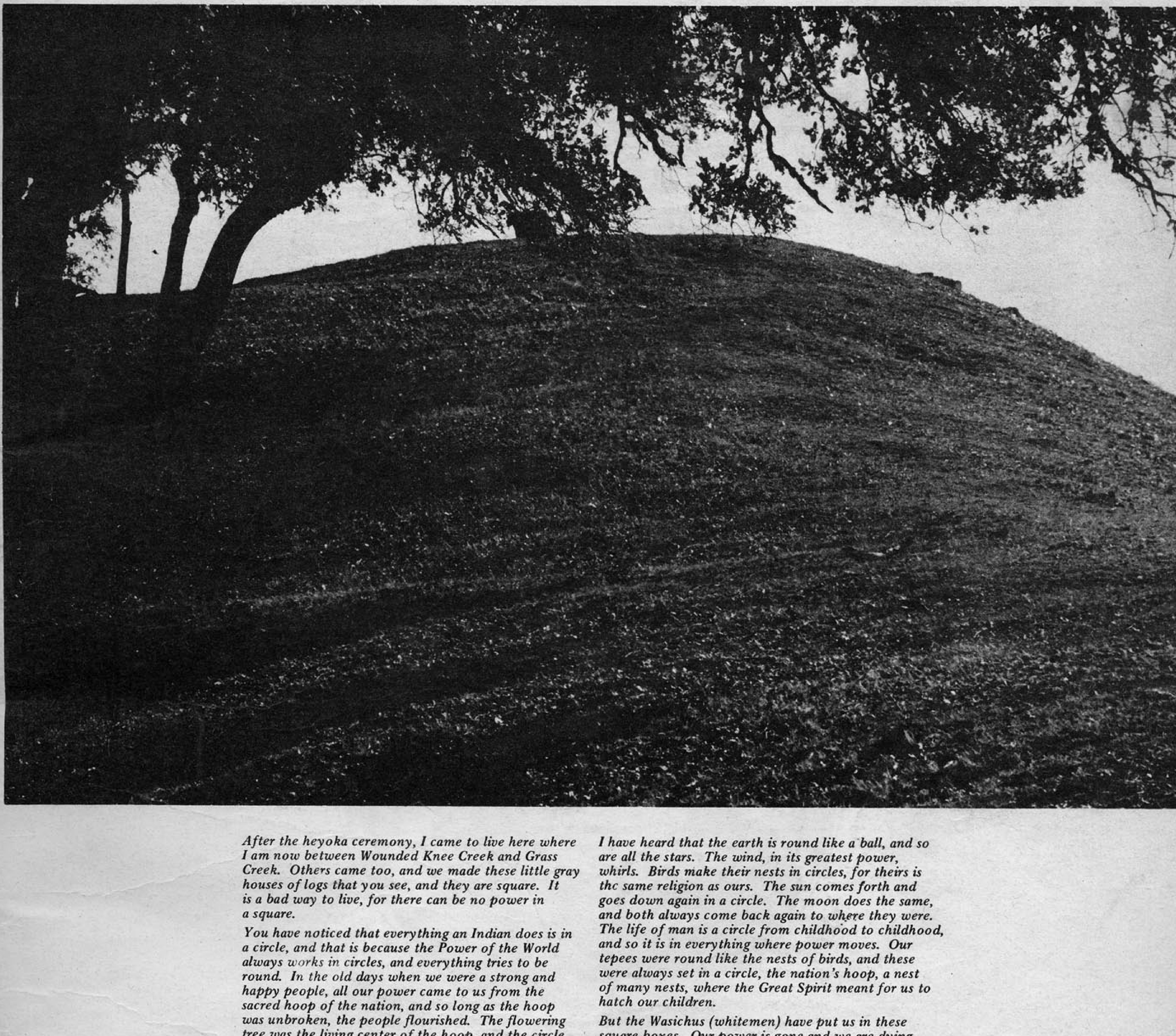

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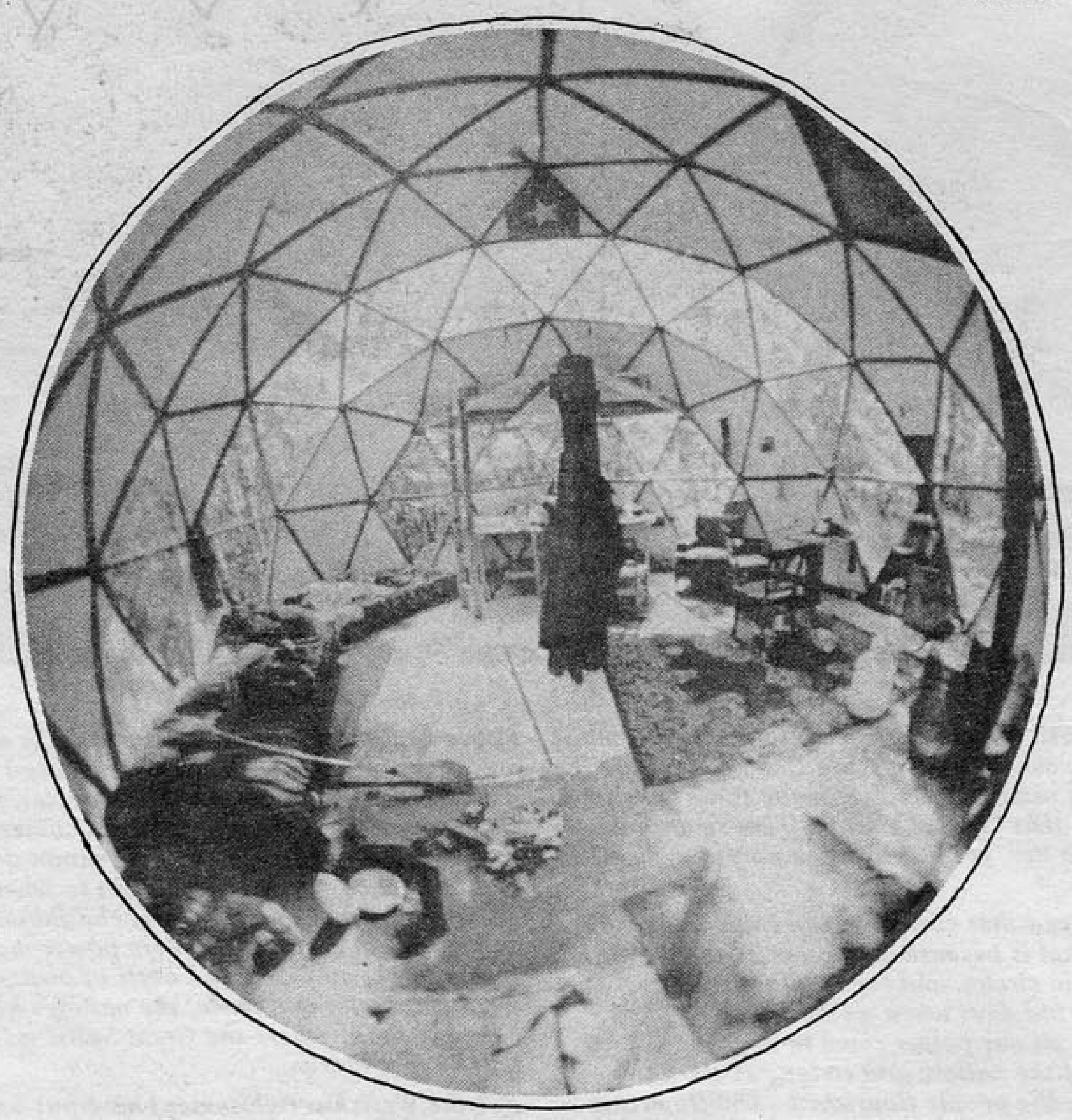

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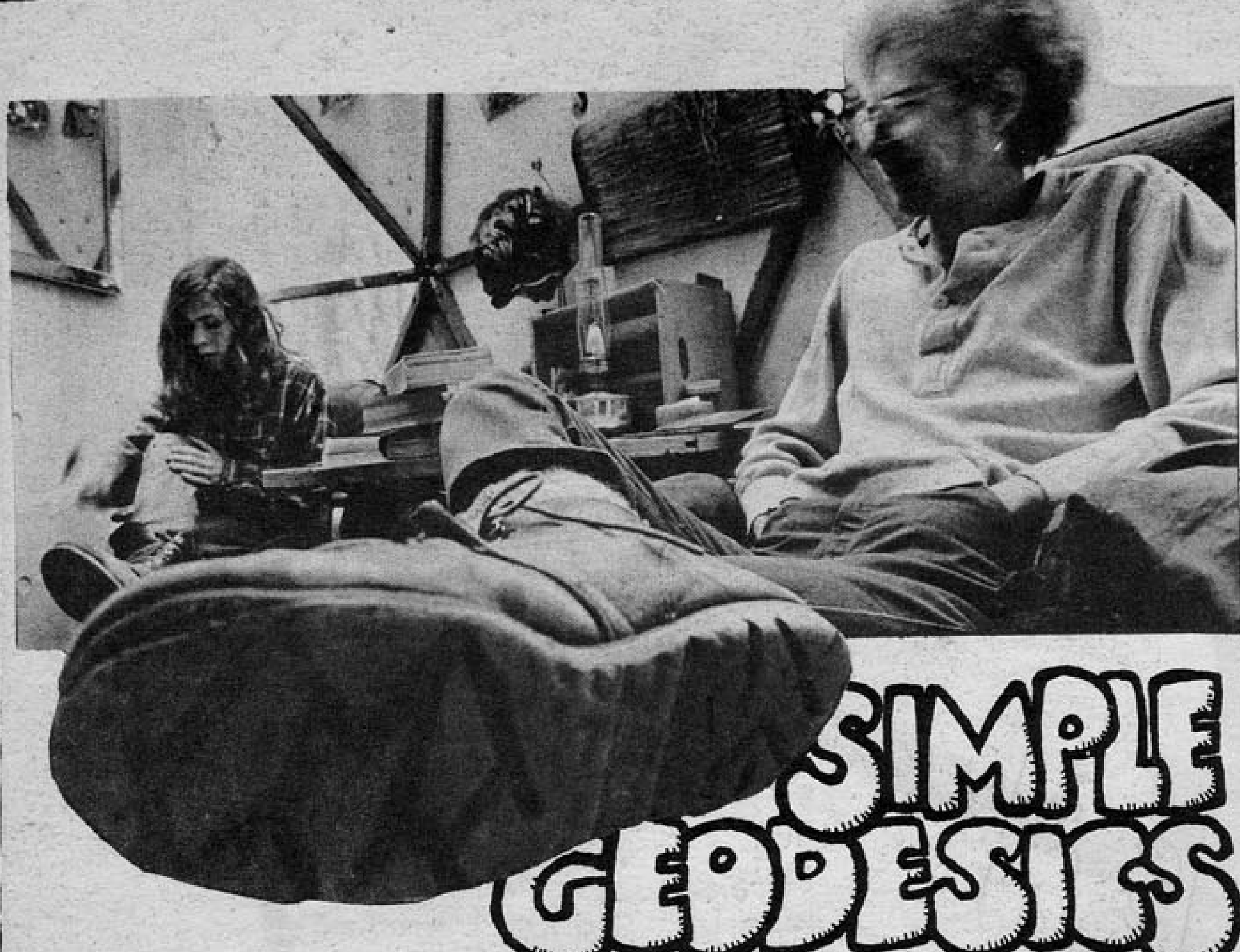

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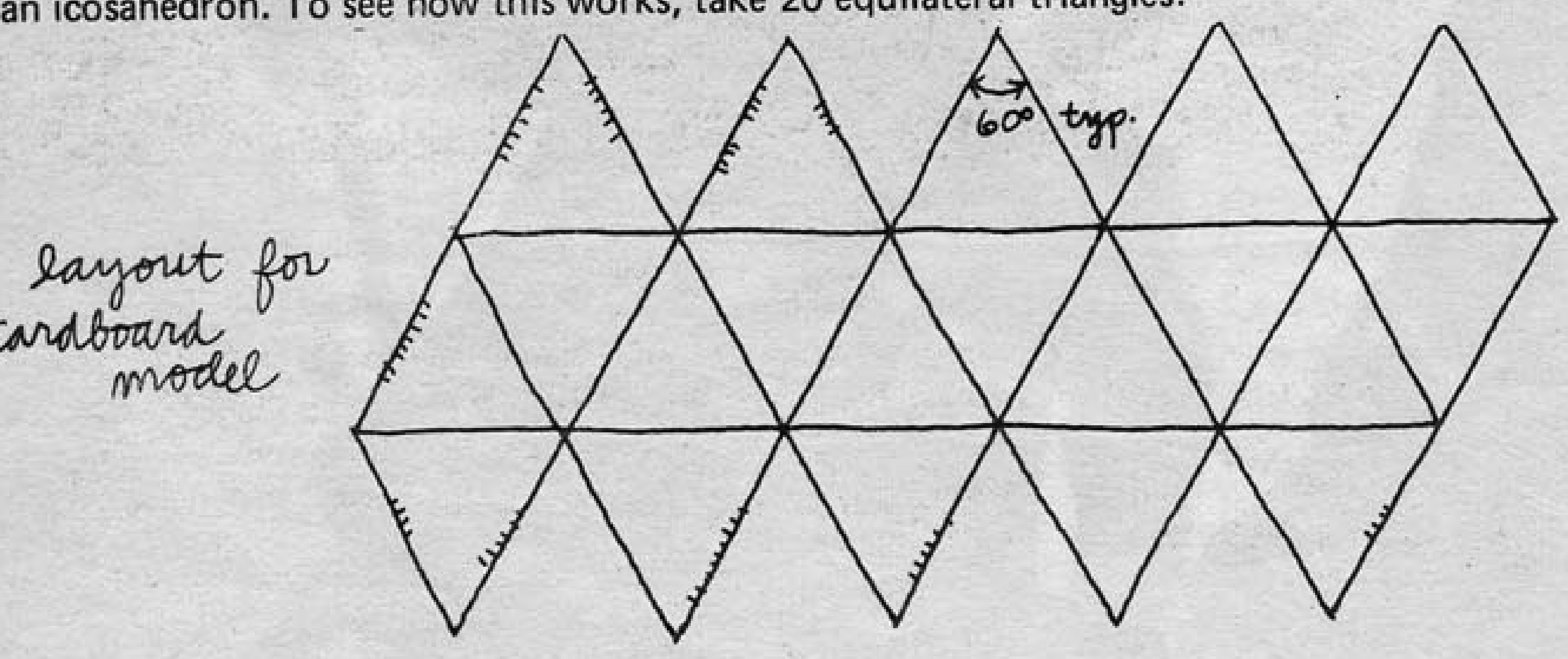


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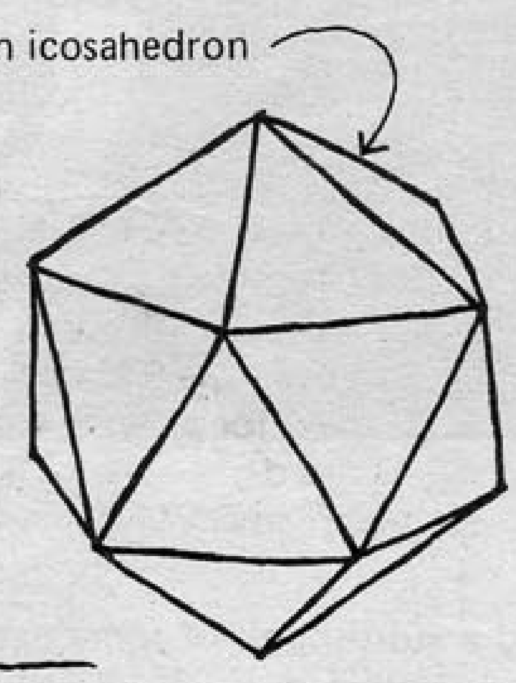

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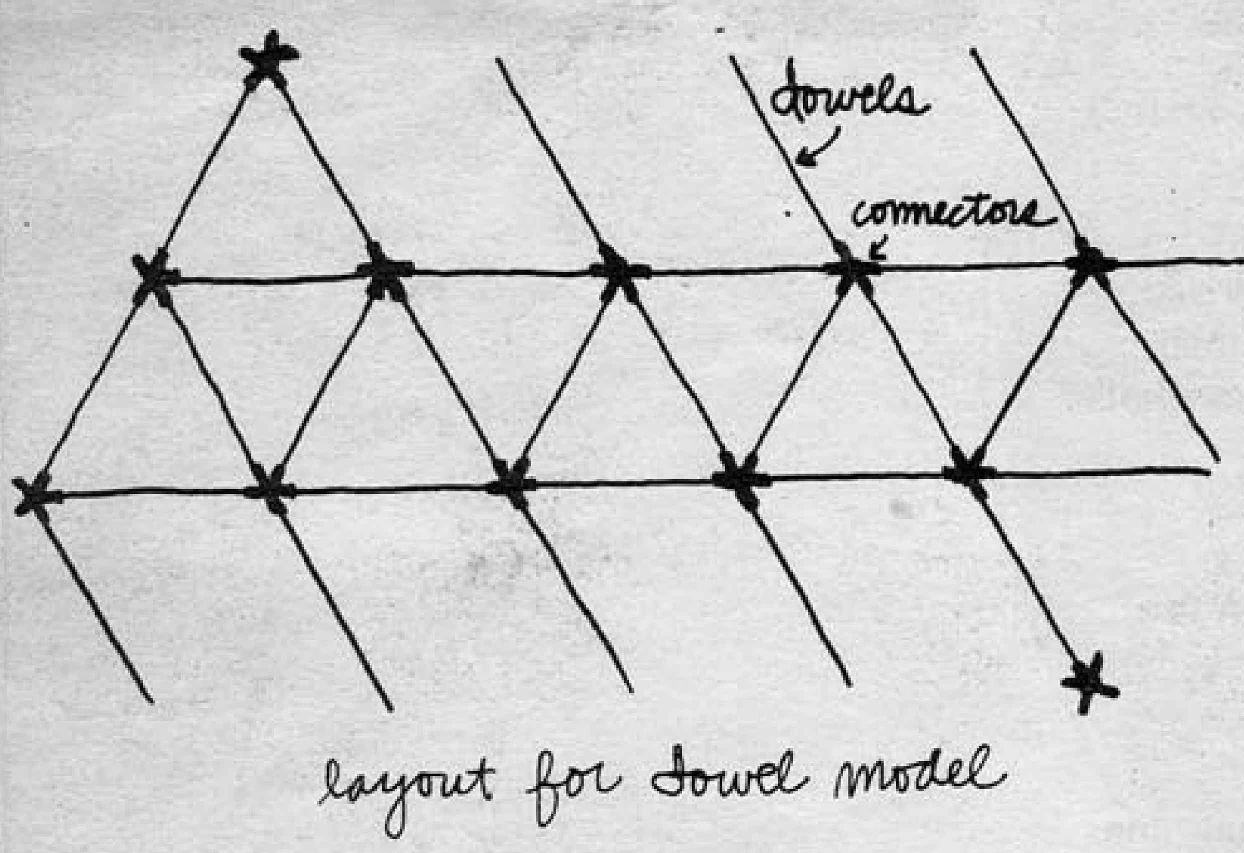


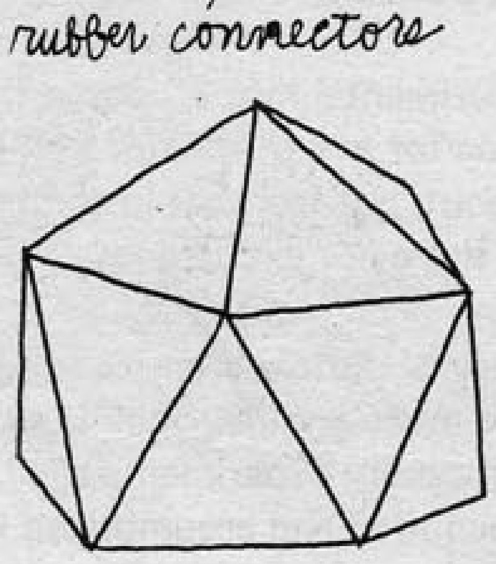

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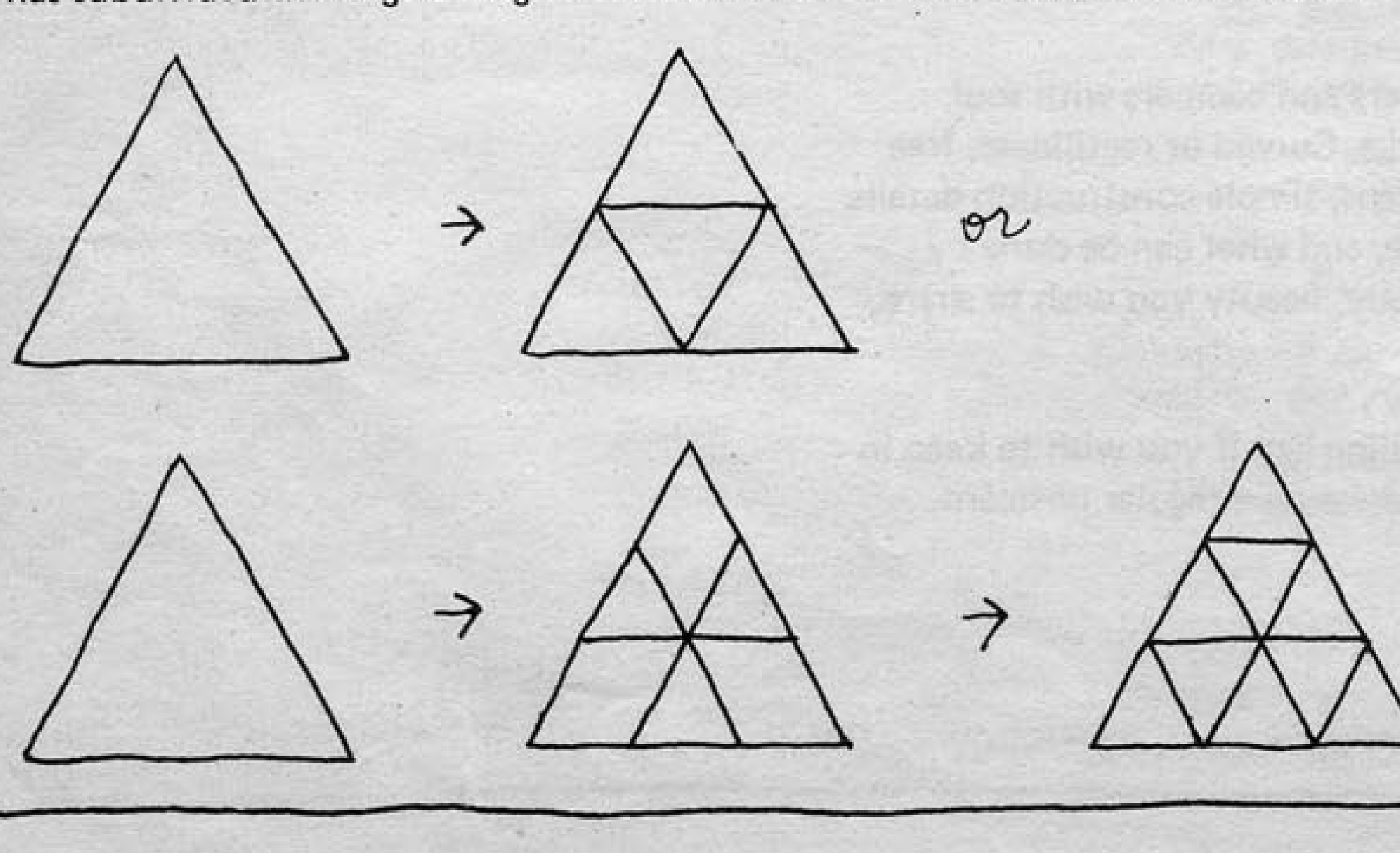




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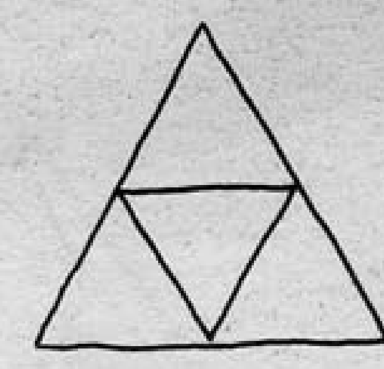

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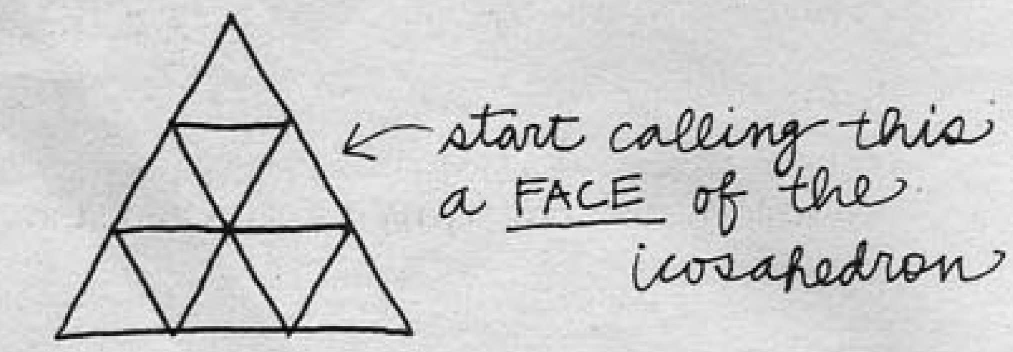


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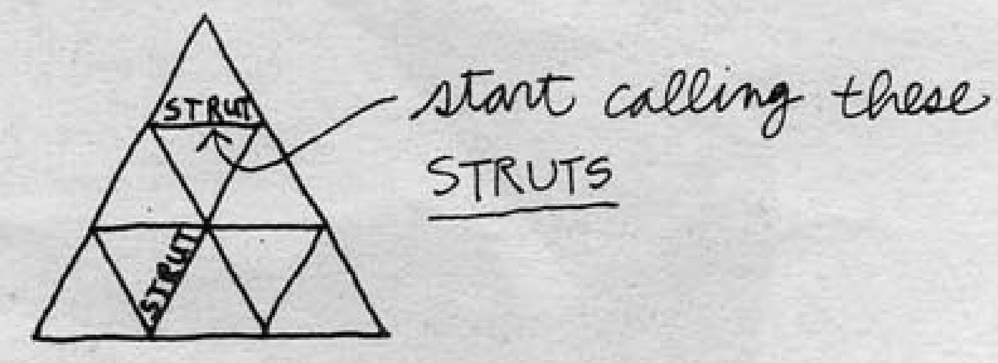
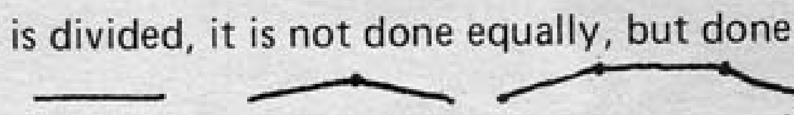



And when the face is divided, it is not done equally, but done so that the faces begin to curve outward: 

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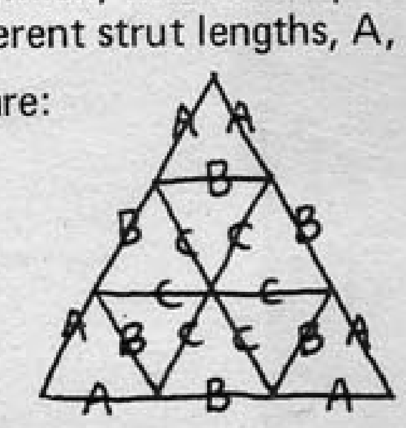

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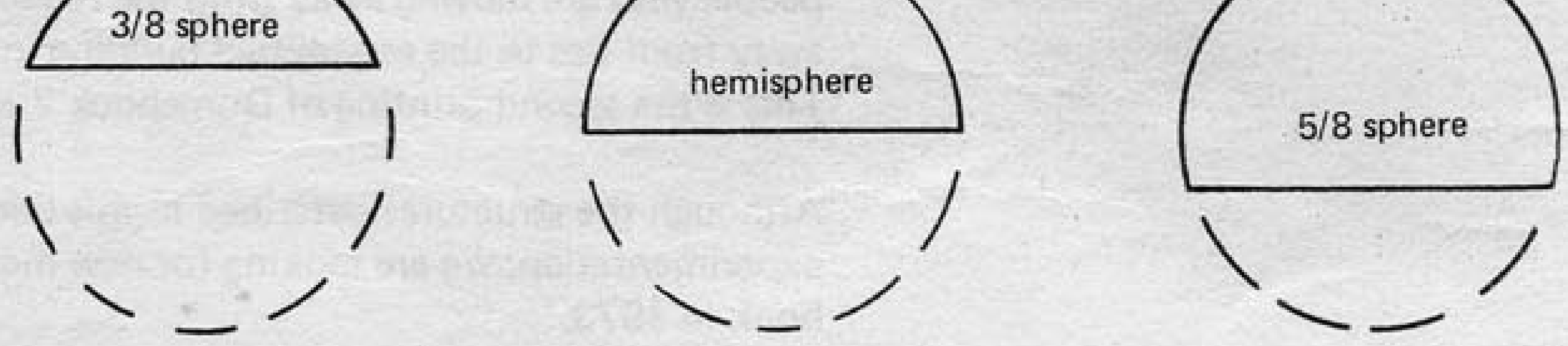


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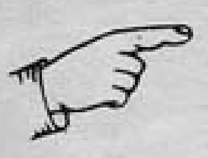
# MODELS

Models are essential. Don't try to build a dome without first making and studying models. However, don't get so involved with models that you never try a real structure.

You can make many decisions by studying the model, and often save yourself full-scale mistakes by trying it first in miniature.

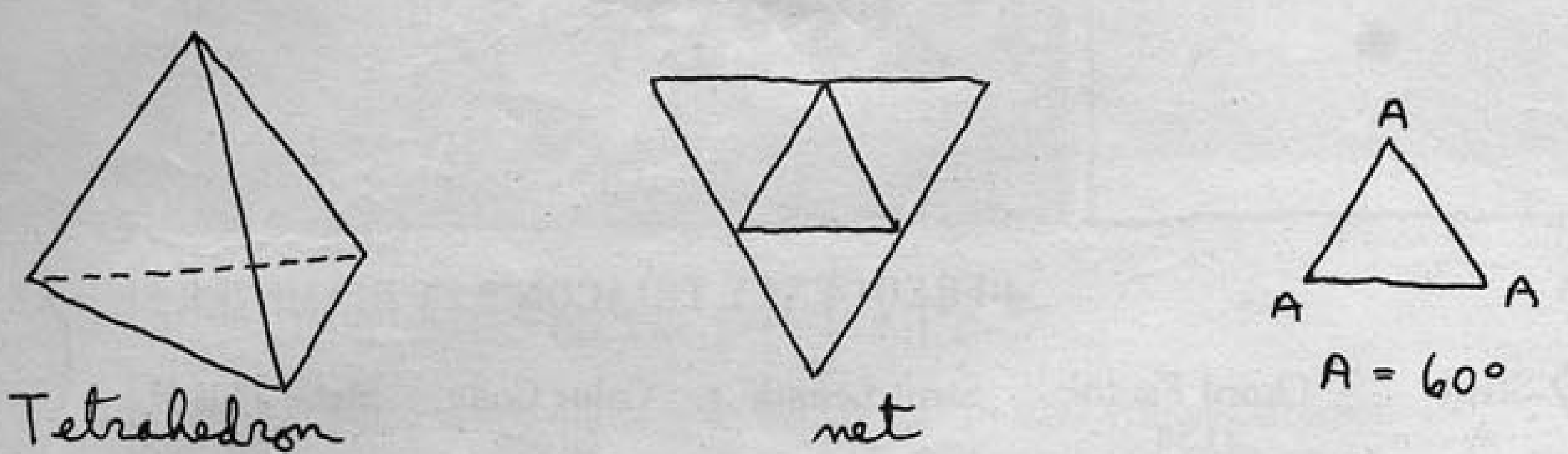


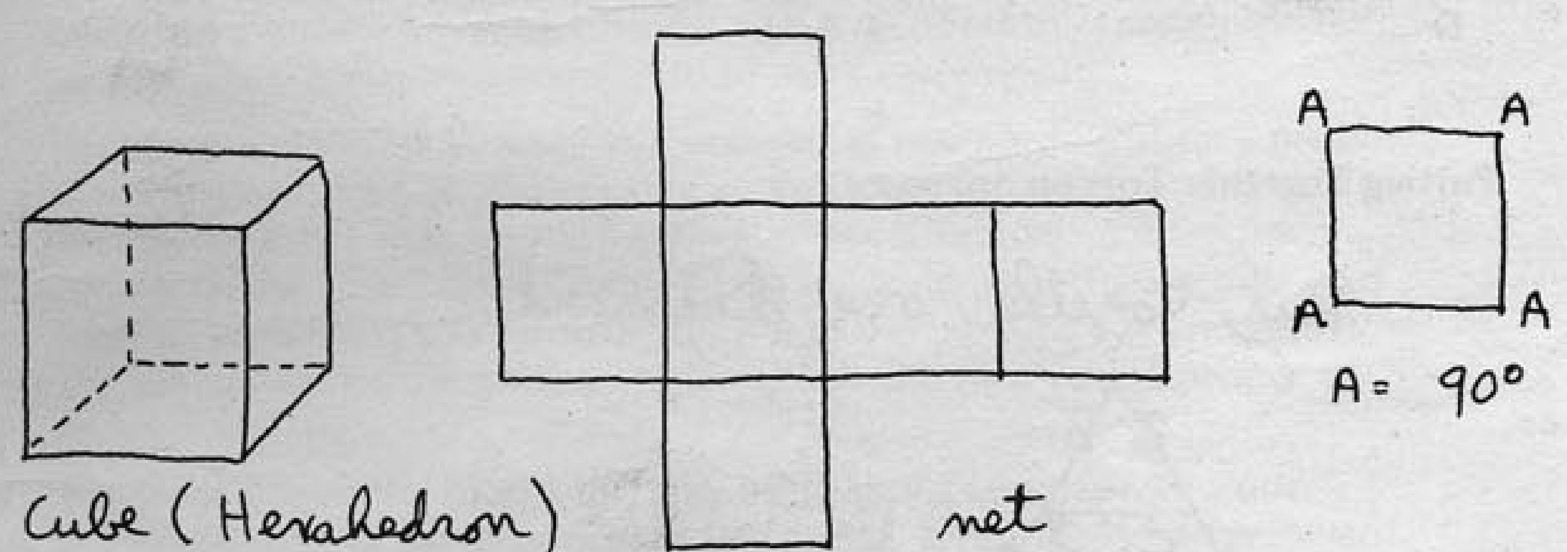
There are two types of models you can easily make:

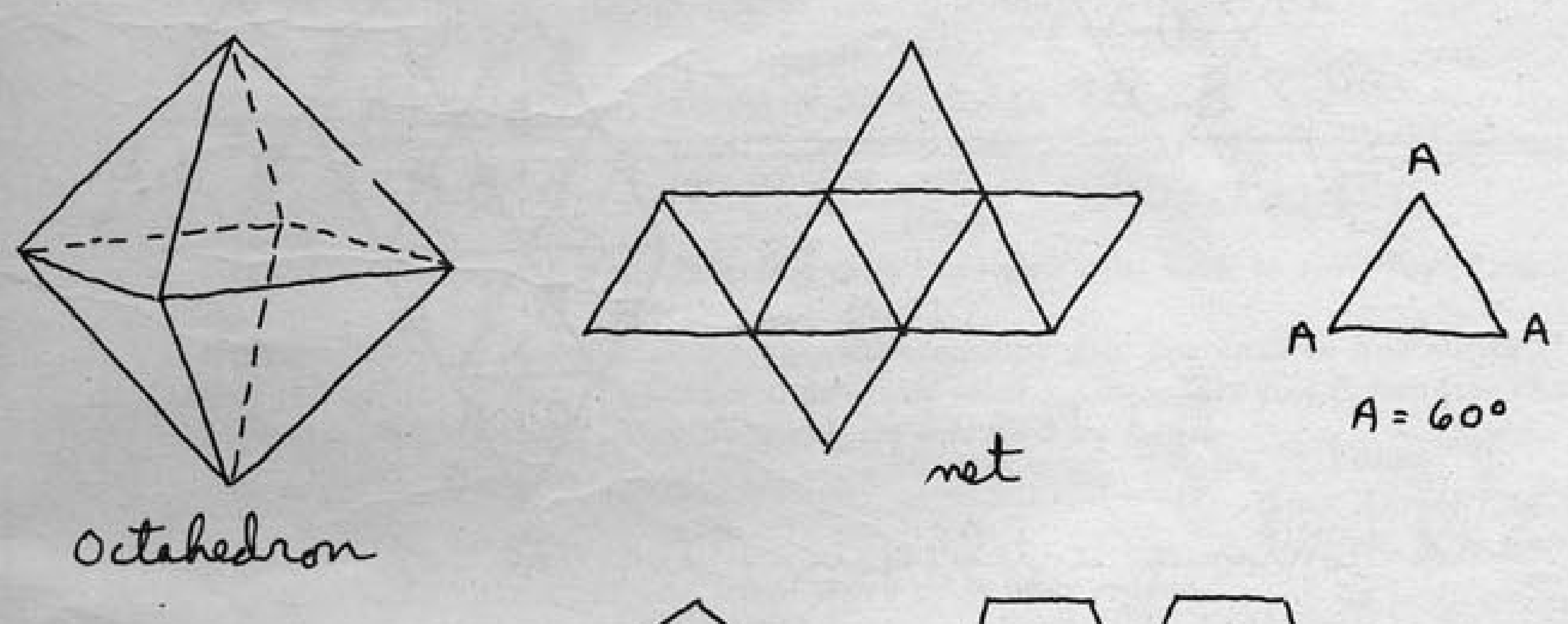
1) Strut models
2) Membrane models

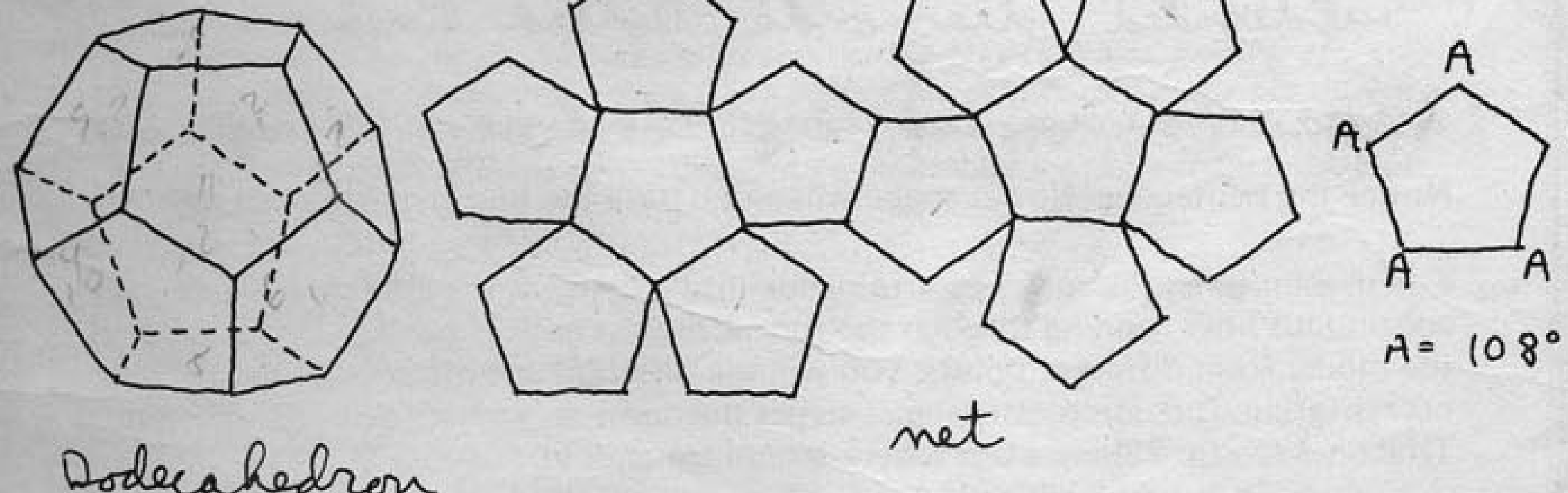
## 5 REGULAR SOLIDS

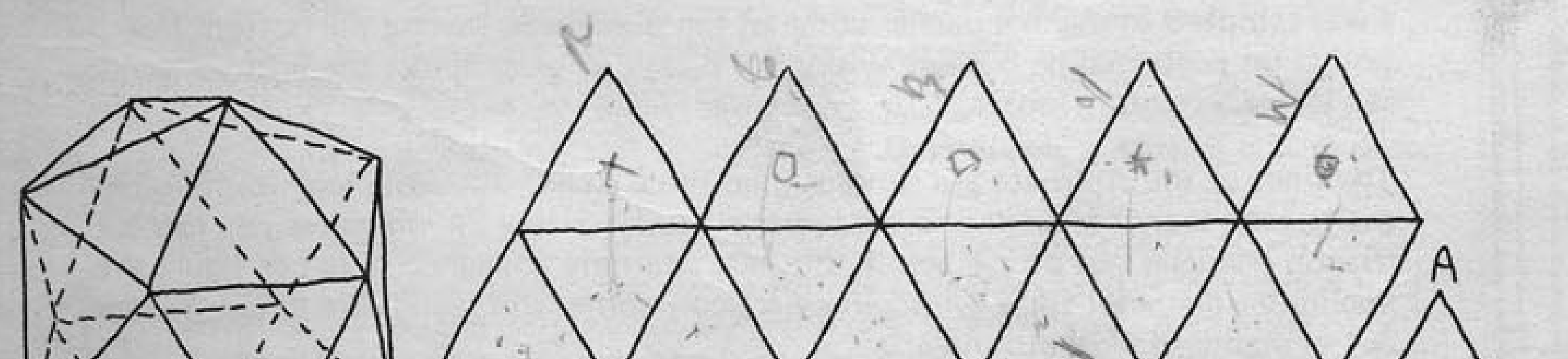
In these sketches, the net is the two dimensional pattern that may be folded to form the polyhedron if you are building a model of cardboard. Length of strut doesn't matter as long as they are all the same. A=Angle.



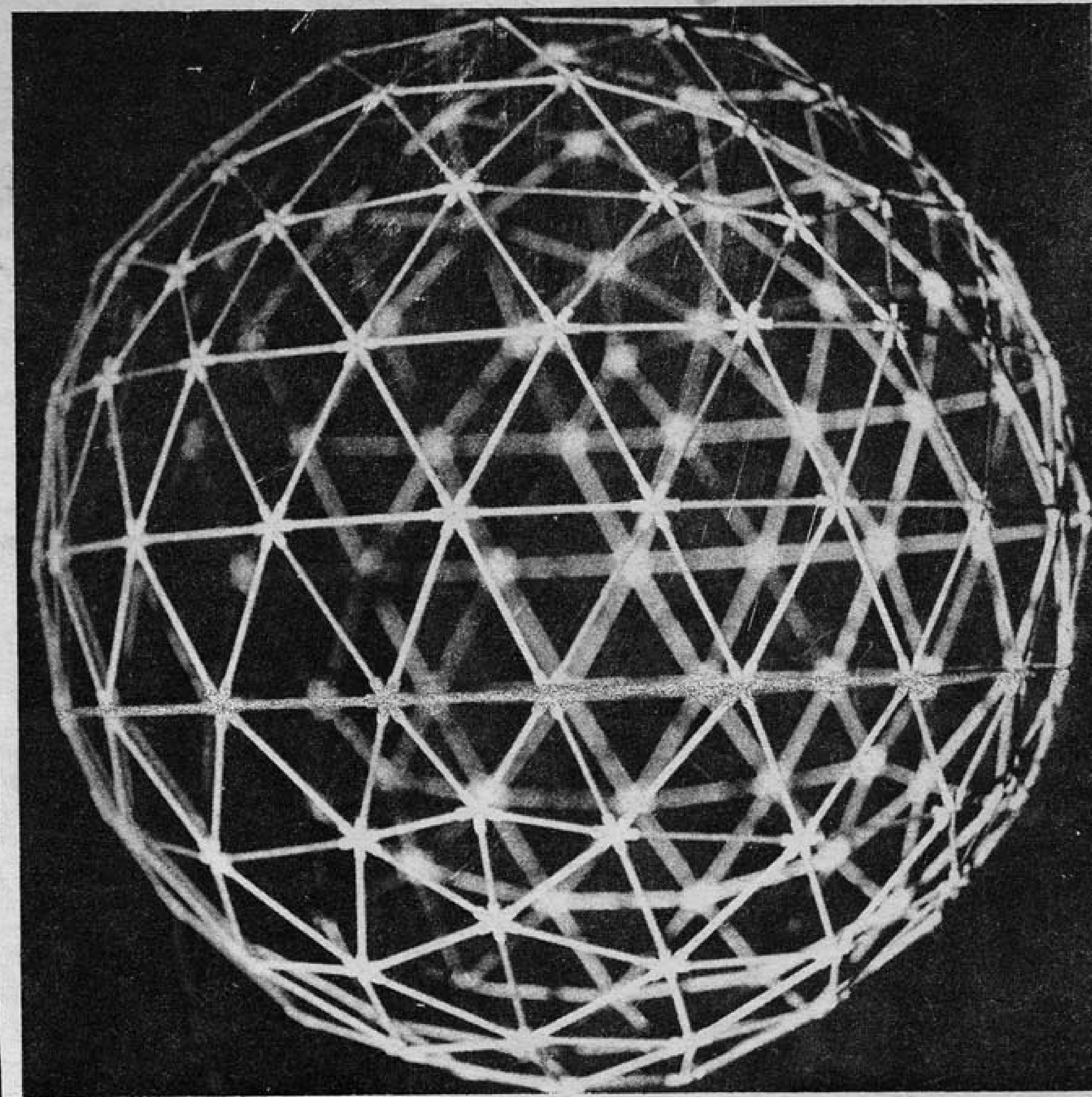




The cube is the basis for most buildings. The icosahedron is the basis for the domes we've built; you'll see the relationship between the icosa and geodesic domes if you make the spherical models. Note: See math books (especially *Mathematical Models*) for archimedean solids and duals - 26 additional shapes.

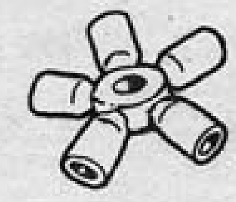




*4-frequency alternate sphere*

### STRUT MODELS

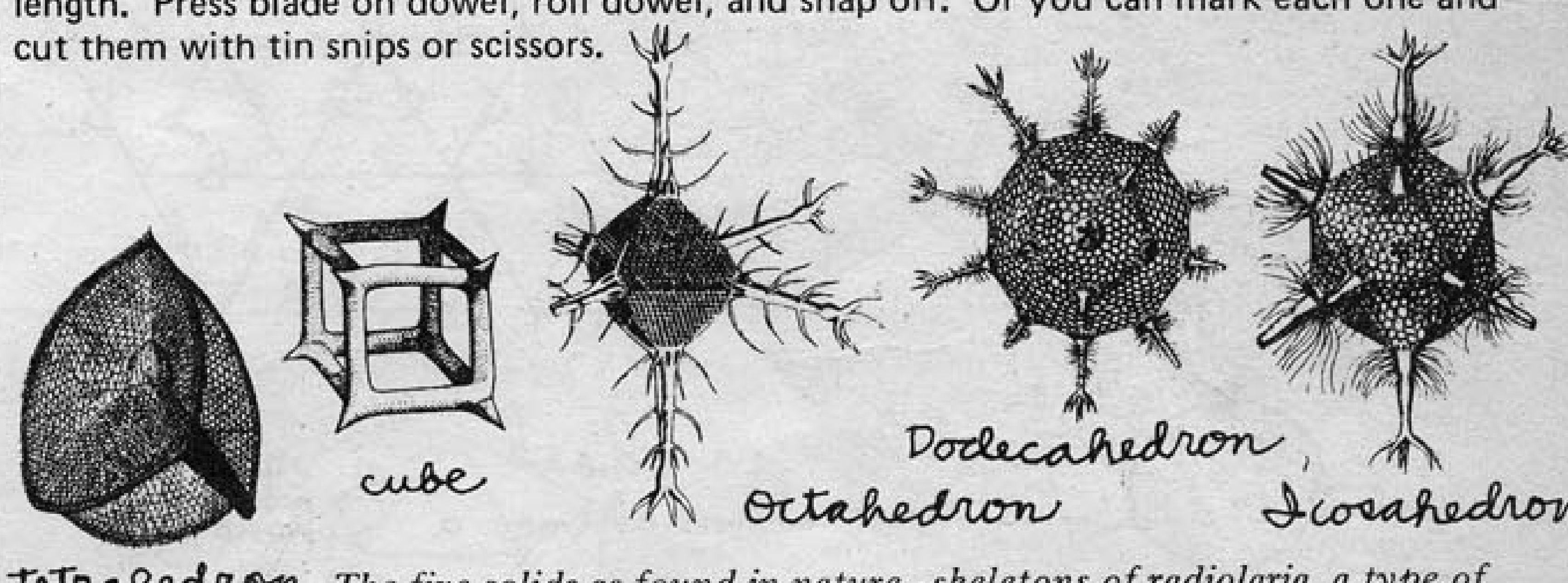
These are models of the structural framework of a dome, made with 1/8" dowels and *Think Sticks* rubber connectors, which you can get from Edmund Scientific Co., 100 Edscorp Bldg., Barrington, N.J., 08007 or from Geodestix, Box 5179, Spokane, Wash., 99205. *Domebook One* caused such a demand for the connectors that both companies were out of stock for a while.



You can get 1/8" dowels at a hobby shop (they're used by model airplane hobbyists) or you can buy one of the Think Sticks kits from Edmund. However, the kits don't have enough connectors to make many models.

You need the 6-way connectors, which are about $4.00 for 50. You can adjust some of these for a few 5-way connectors you need by snipping a tip off. If you make the models described on the next page, you'll need 100 connectors for the alternate sphere, 150 for the triacon sphere.

The dowels are about 5-10 cents each for 3 ft lengths. You can cut them on a wood board with an X-acto knife. Set up a small stop so you cut each exactly to the same length. Press blade on dowel, roll dowel, and snap off. Or you can mark each one and cut them with tin snips or scissors.



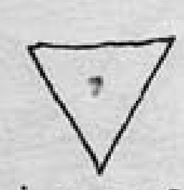

*The five solids as found in nature—skeletons of radiolaria, a type of plankton, as shown in D'Arcy Thompson's* On Growth and Form, *from left to right: Callimitra agnesae, Lithodubus geometricus, Circoporus octahedrus, Circorrhegma dodecahedra, Circognia icosahedra*

### about structure

One of the most instructive things you can do when beginning to learn about structure is to assemble the five *regular solids*. These are the only five polyhedra (a polyhedron is a solid bounded by planes) with all edges of equal length, all faces (planes) exactly the same, all face angles equal, all vertices identical, and all dihedral angles equal.

When you assemble these with dowels, you are in effect hollowing out each solid, and since you are using flexible connectors you will learn some interesting structural facts.

When you put them together you will notice that the tetrahedron, octahedron, and icosahedron are perfectly stable, even though joined with flexible connectors, and the cube and the dodecahedron are unstable. To stabilize the cube, you must put a diagonal dowel across each square; to get it completely stable you find that you have inserted a tetrahedron inside the cube. To stabilize the dodecahedron you must put 5 spokes into the center of each pentagon.



### triangles make structures stable

From this you learn that triangles are necessary for structural stability (a piece of plywood spanning a rectangle provides triangulation in all directions in one plane due to laminated cross layers of wood).

# MODELS

### Making Model Spheres

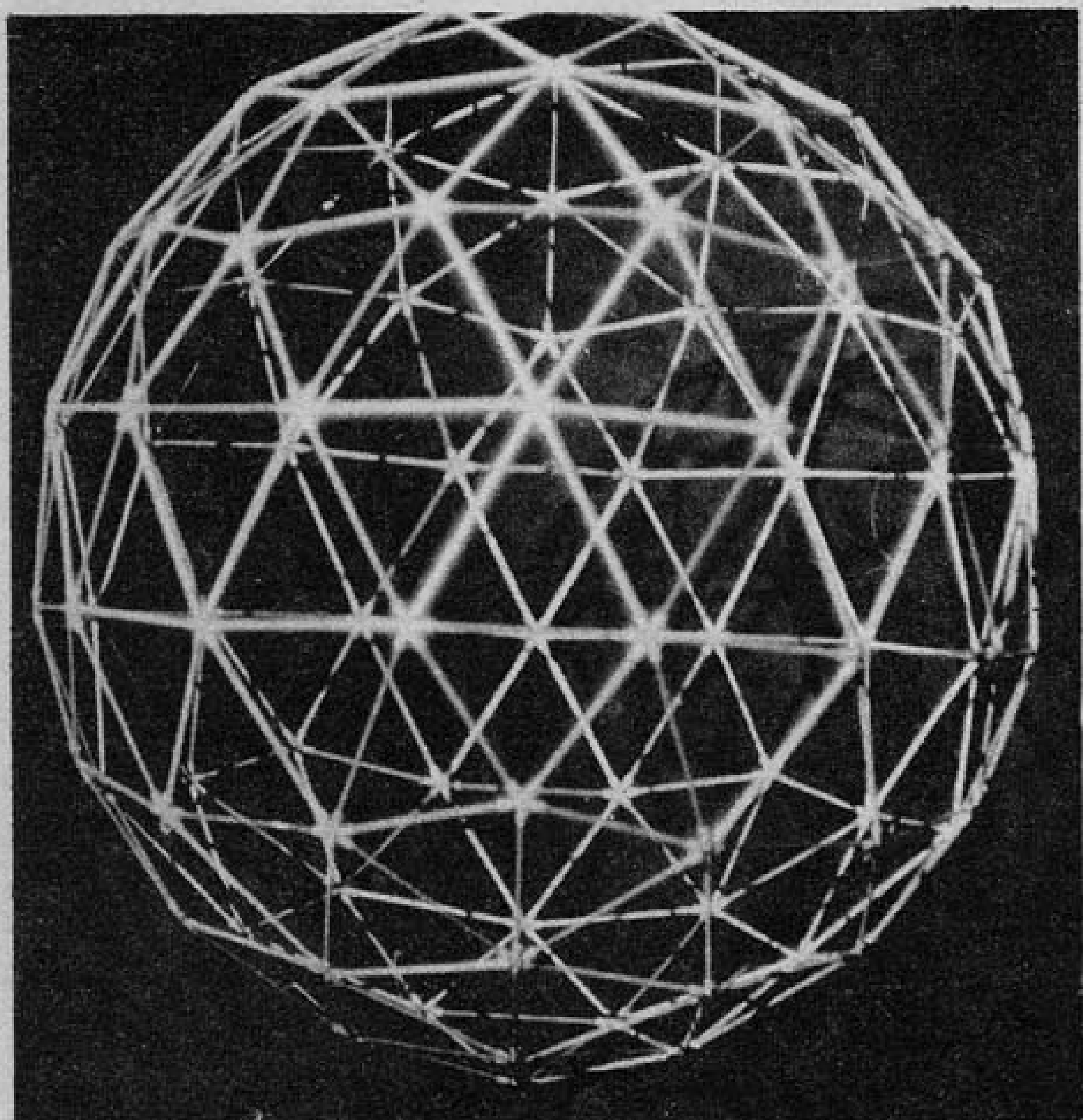
A dome is a portion of a sphere. If you make a sphere model you can see where to cut it off to make a dome, how to orient it to the earth, and trip out on the different patterns.

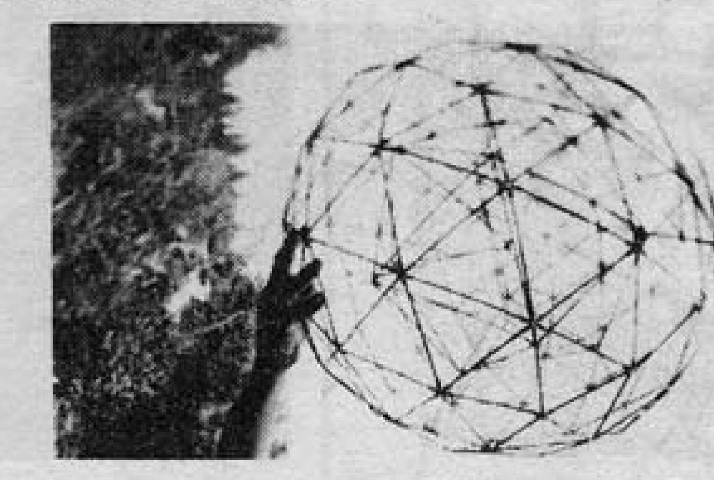
Here are instructions for two types of geodesic sphere models: the *alternate* and the *triacon*. Both models are the same diameter and can be studied with respect to making full scale domes.

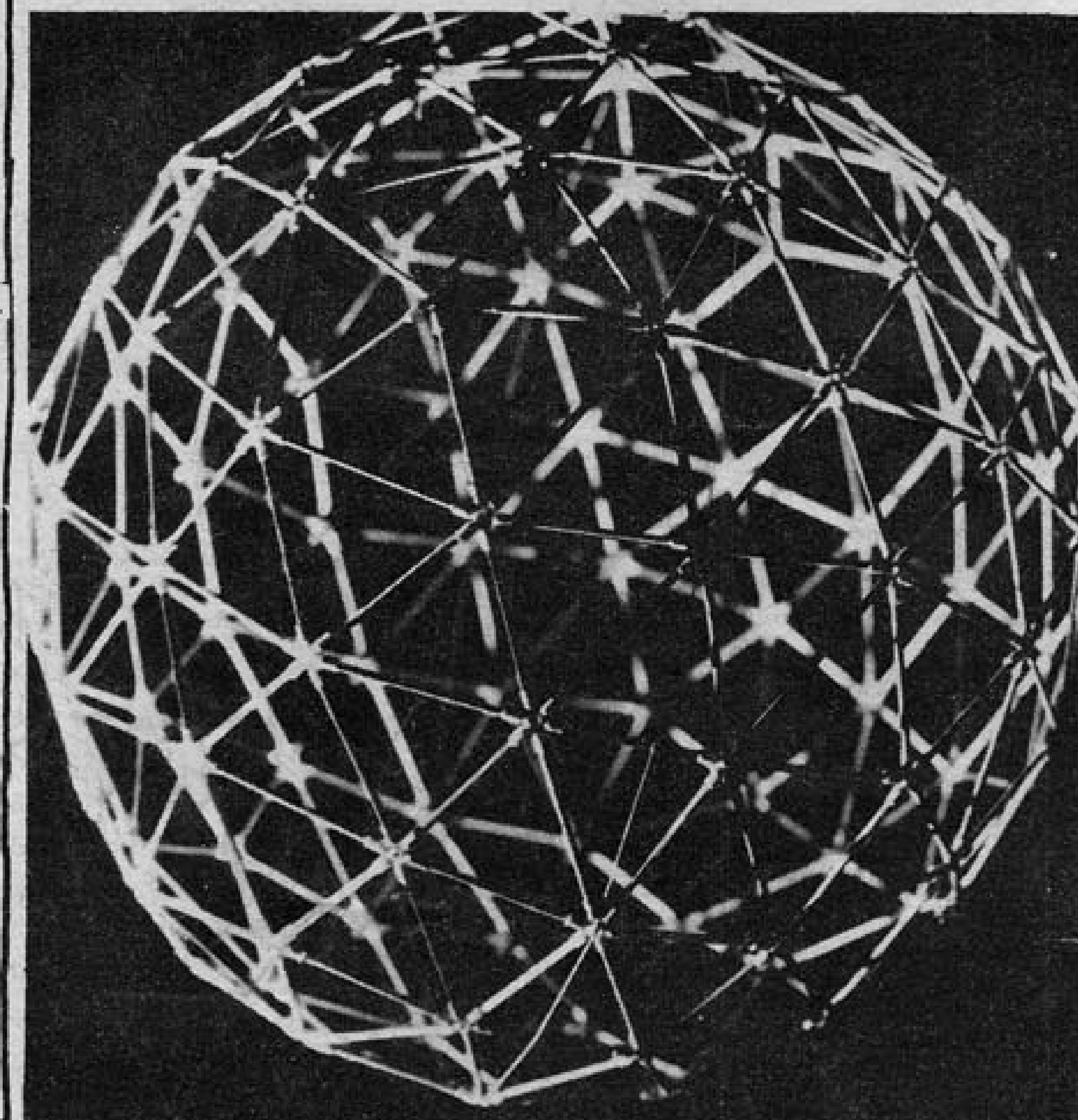
For each model, we give calculations for the strut lengths. It would be a good thing if you checked these out for yourself before cutting dowels; to do this you get chord factors for the *alternate* on p. 109 and for triacon on p. 110.

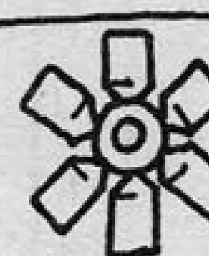
Multiply the chord factor times the desired radius in inches to get the chord length; then—*important*—subtract the length of the connector, which is 3/8" for rubber connectors, to get strut length.

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 |

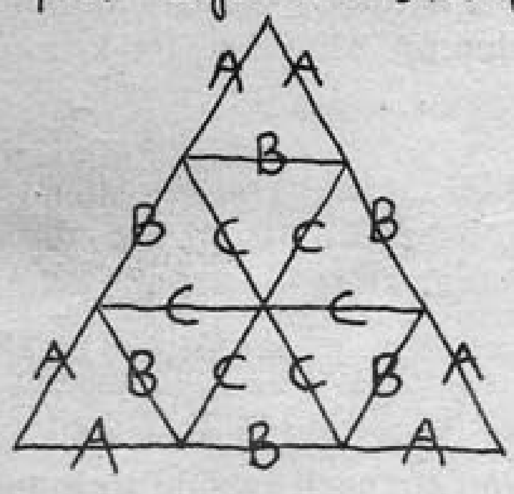
**We have subtracted 3/8" (.375) for connector*

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

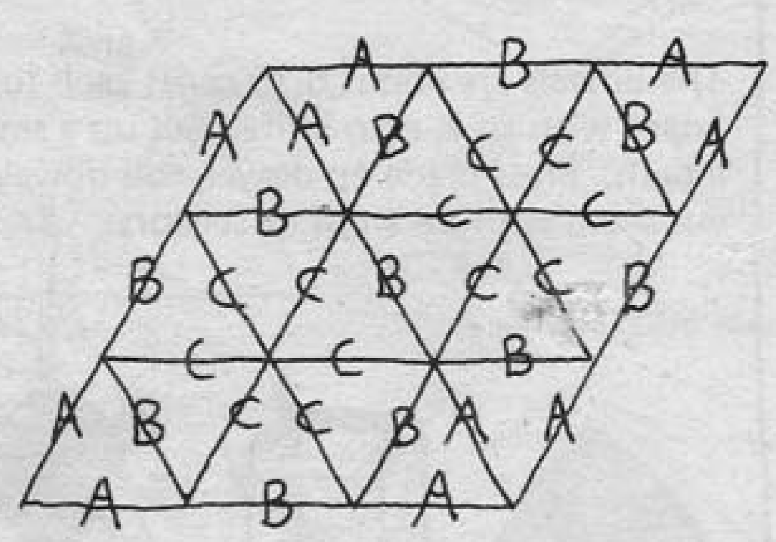
4183
−375
3808 = 3 13/16"

**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.

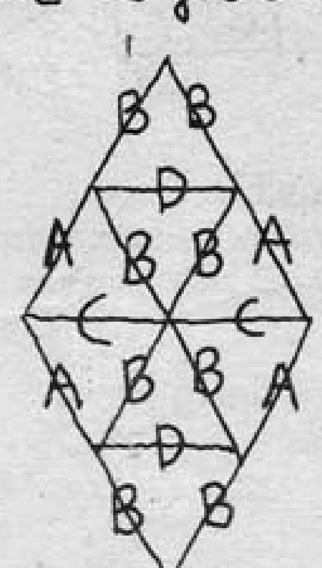
**4-FREQUENCY TRIACON 2 FT DIAMETER SPHERE**

| 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 |

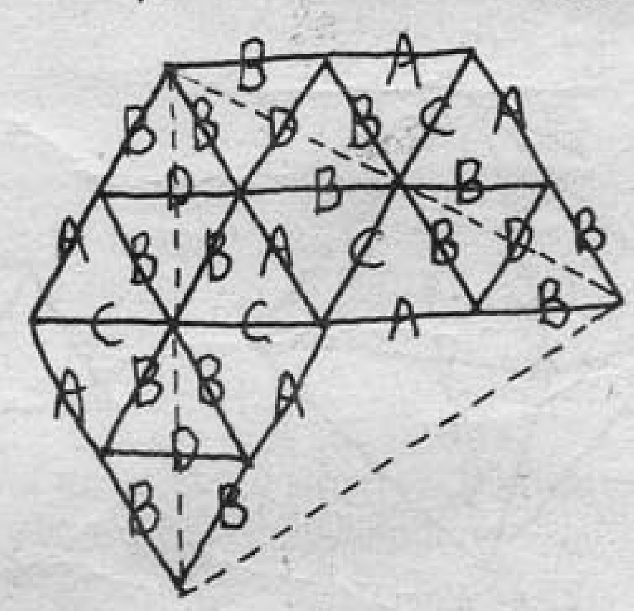
**See left*

**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.

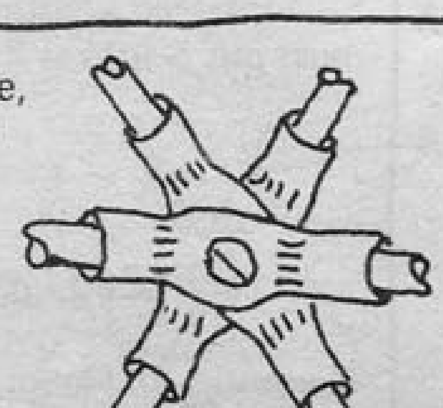
The triacon sphere is not as easy to divide into a dome as the alternate, where continuous lines running through the sphere suggest cut-off points. If you suspend the model from different points, you will see different cut-off possibilities, all necessitating truncation of triangles to get the dome to 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 6' 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.

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.



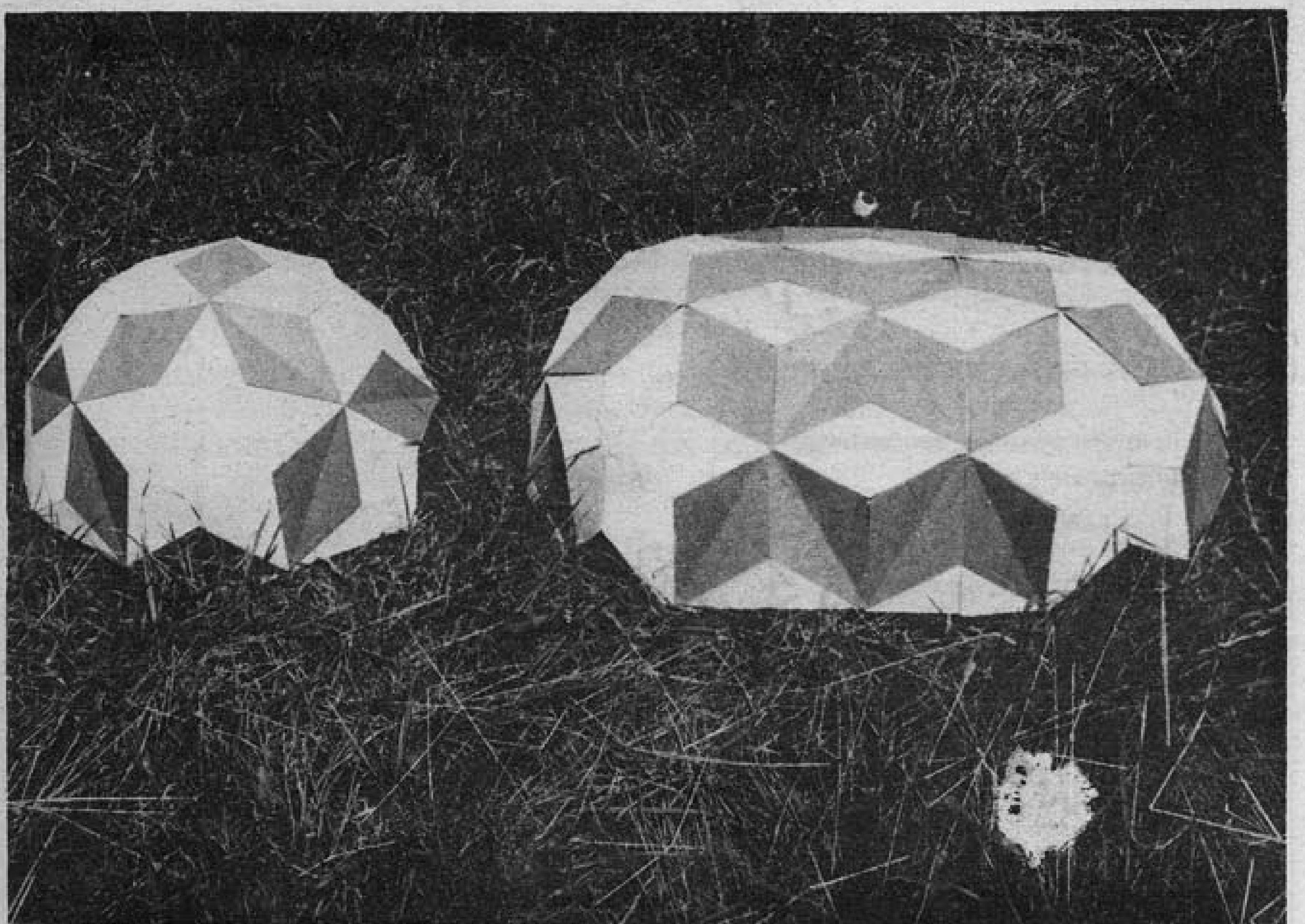
These two models are useful geometries for home domes, 25-40' diameters.

Model supplies:

—styrene sheets, clear rods: Kemtron 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 5179/Spokane, Washington 99205, 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's 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:

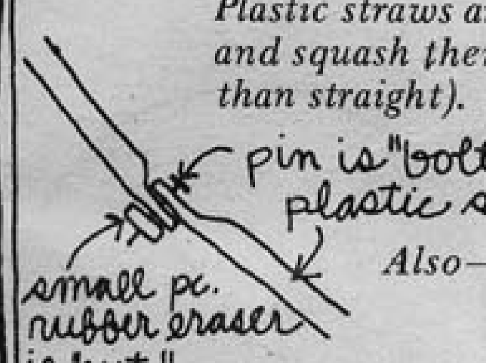
—you can string straws together with sewing thread. Difficult, but it makes delicate models

—hot melt glue is useful—it sets up in 30 seconds.

## two letters on plastic straw struts:

*Geod-Stix are great for models, but they cost and you have to wait for them.*

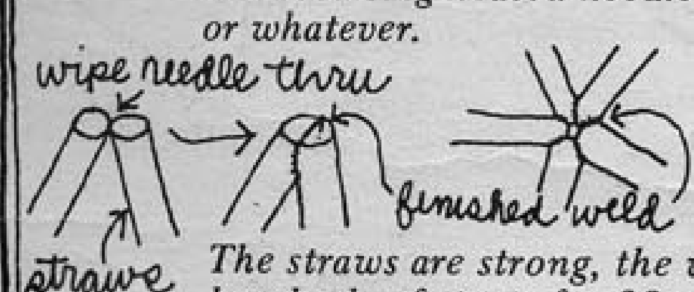
*Plastic straws are cheaper and easier to come by. Dip the ends in hot water and squash them flat. Puncture them first with a pin(safety pin is handier than than straight). Fasten them with staples inserted by hand.*




*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 in miniature from the soda straws; "weld" them together at hubs using heated needle. You can put a handle on the needle with tape or whatever.*




*wipe needle through point where straw touch straws finished weld*

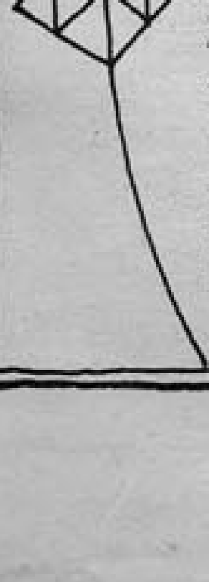
*The straws are strong, the welds are stronger—no hubs needed, you get hundreds of struts for 39 cents (big boxes like restaurants use). Try different colors for strut coding, tissue-paper mucilaged on for window and panel layouts—these models are so cheap and fast you get into them right away and hang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

*Thanks for* Domebook One.

*Bob Bridge*
*Harry Simon*

*Gary Broadway*
*Ganges, B. C. Canada*

## tetrahedonal kites



*I think* Domebook II *should include a page on recreation for the domeowner and some model building experience for the domeplanner: tetrahedonal kites! They are the most stable highest flying kites around. Alexander Graham Bell built huge 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 tetrahedon, 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!*

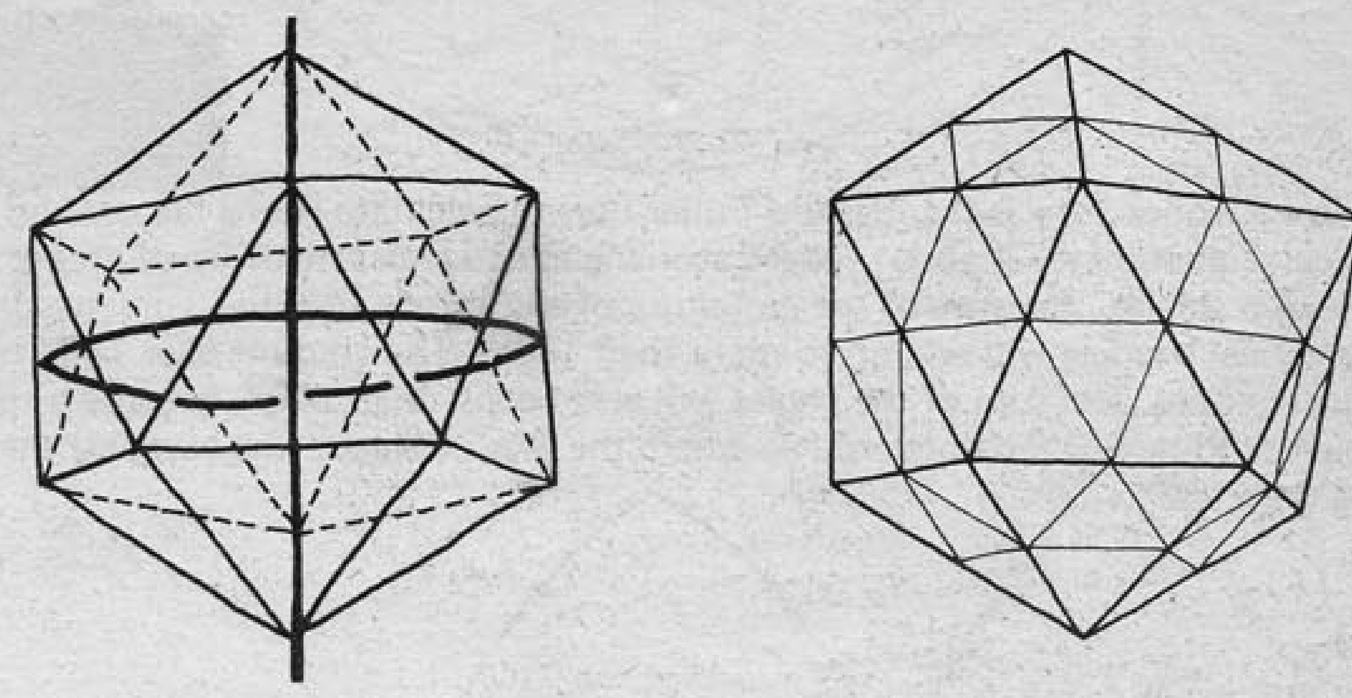
*Yours truly*

*Robert W. Easton*
*Keene, New York*

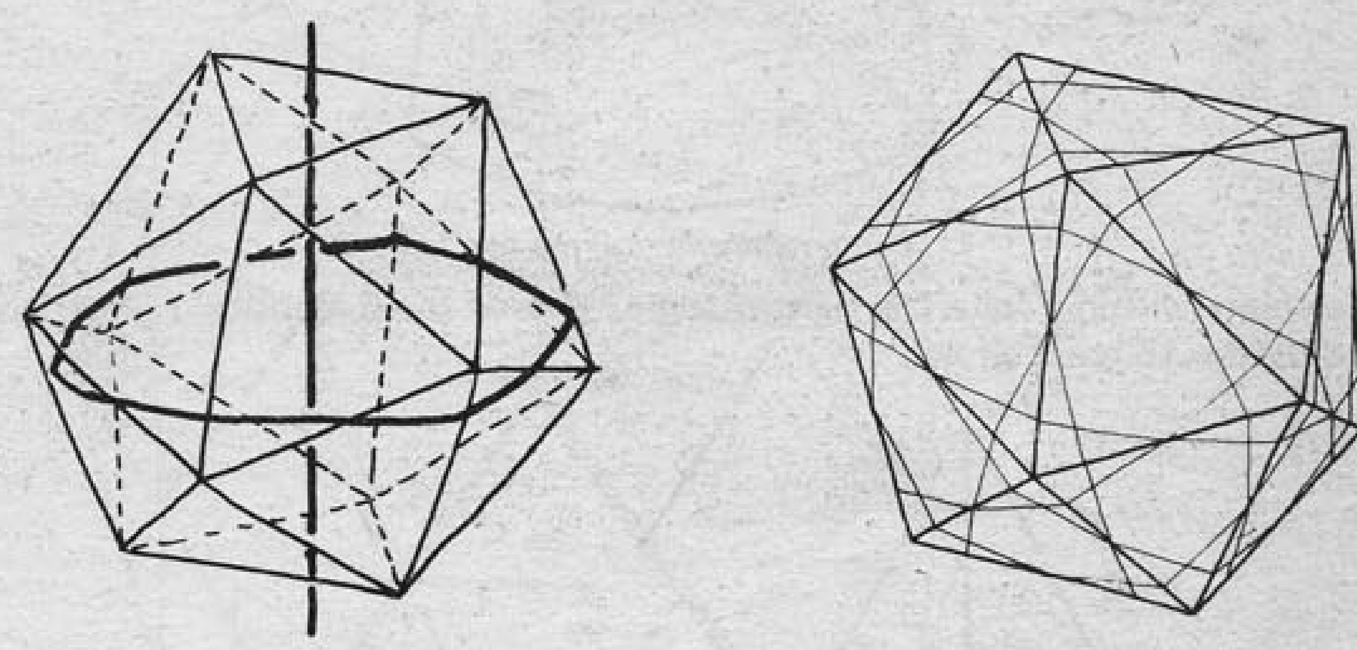
# great circles

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.

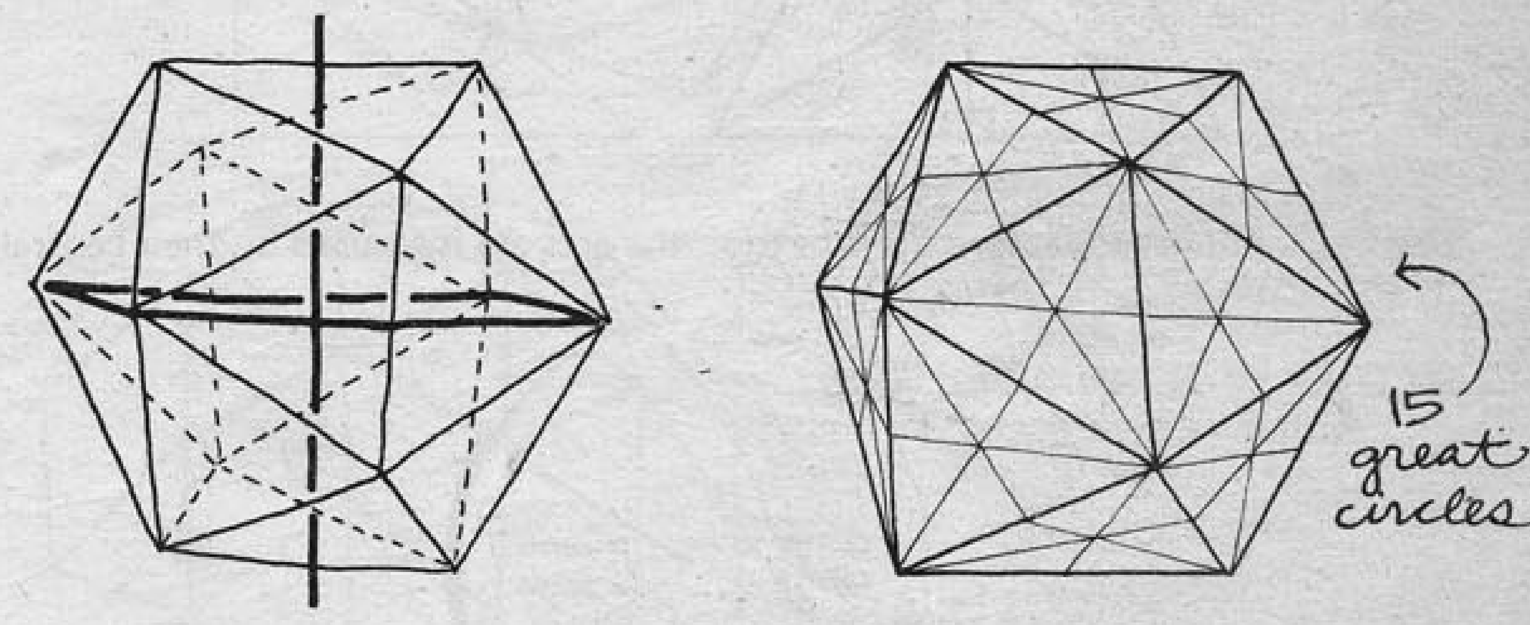
Fuller has discovered that there are 31 great circle planes produced by different rotations of the icosahedron:



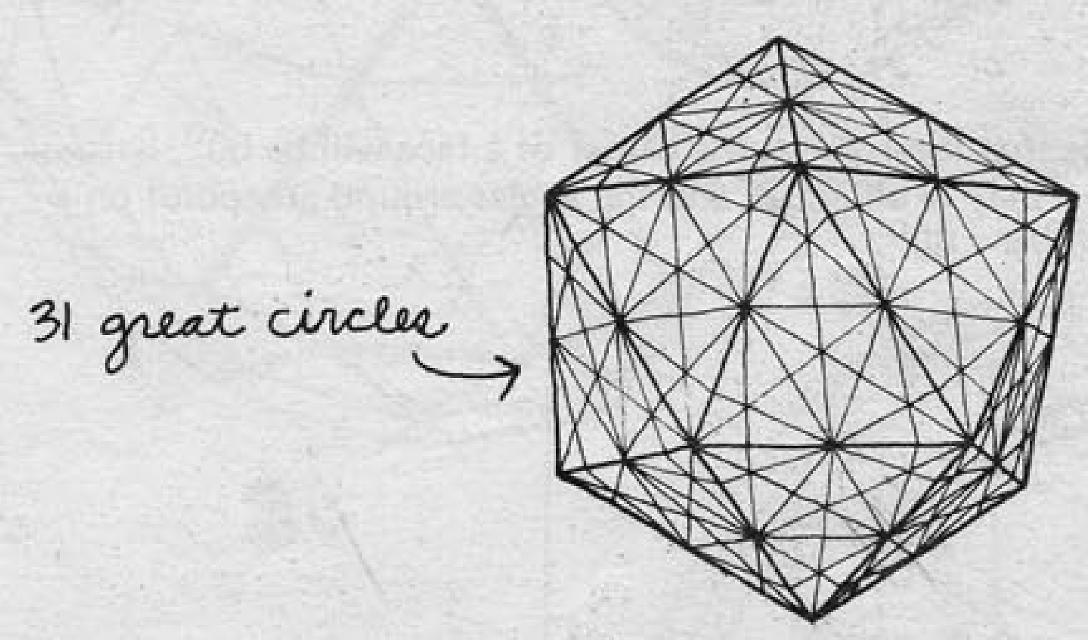
Rotation on axis through opposite vertexes produces six great circle planes.



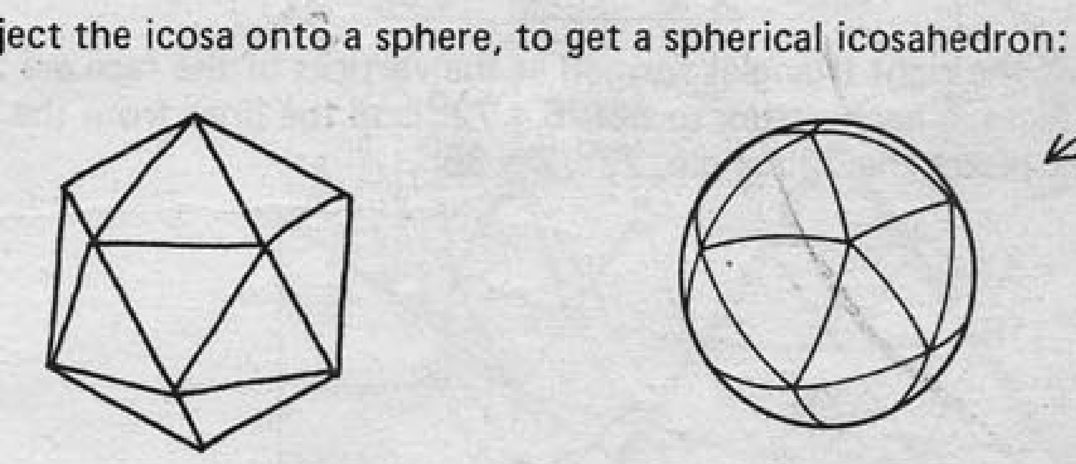
Rotation on axis through centers of opposite faces produces ten great circle planes.




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

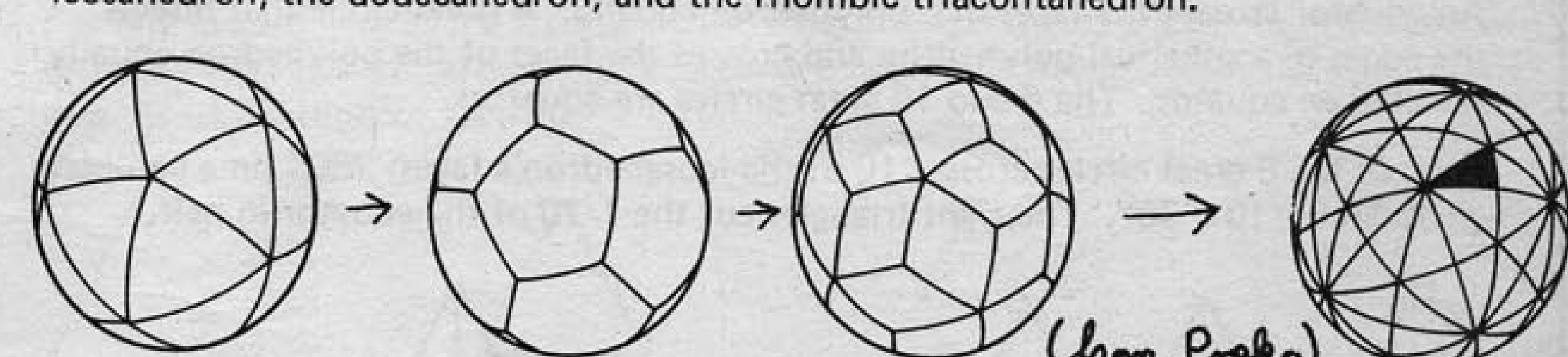



You can project the icosa onto a sphere, to get a spherical icosahedron:



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.



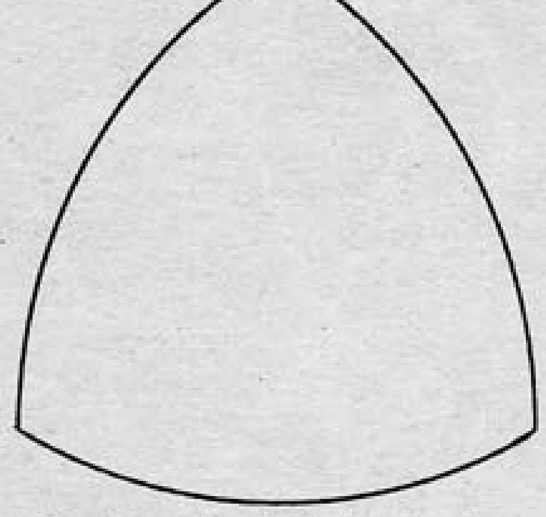

Rotating the spherical icosahedron about different axii results in a subdivision of the surface for which all line segments are portions of great circles and for which all great circles are completely represented.

In the triacon 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.

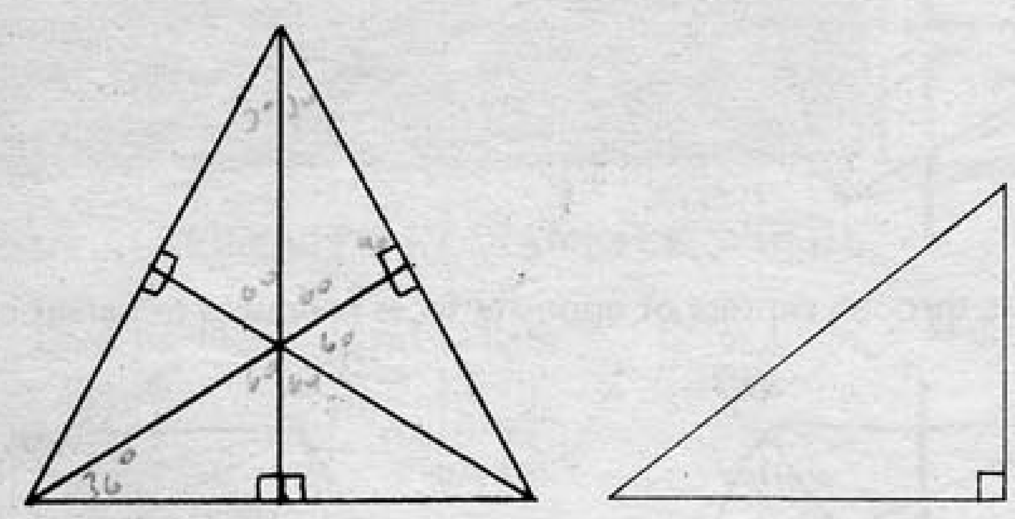
# Spherical Trig

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°.

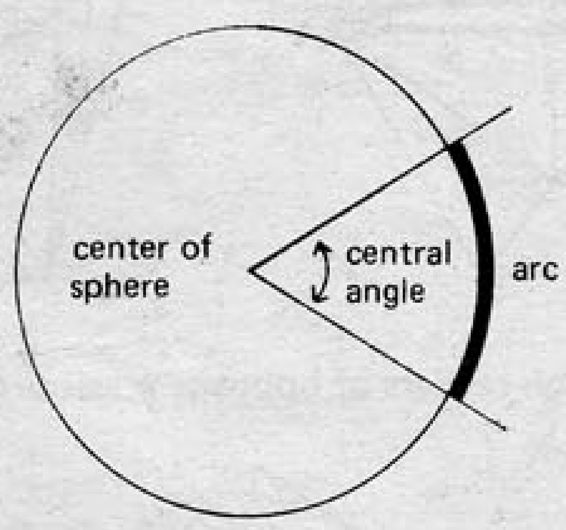


*Equilateral spherical triangle.*

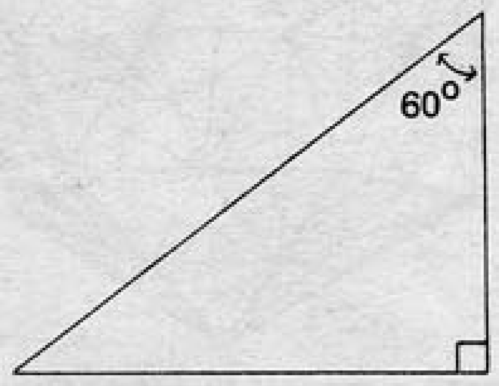
You calculate within a spherical right triangle. One of the 6 identical right triangles formed by the 15 great circles.



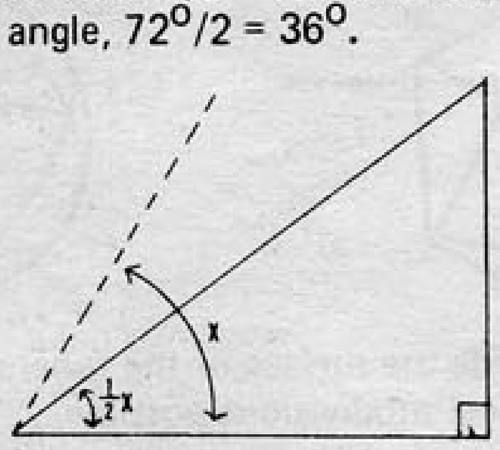
Degrees are used to measure the arcs too: the arcs are measured by their central angle.




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°.

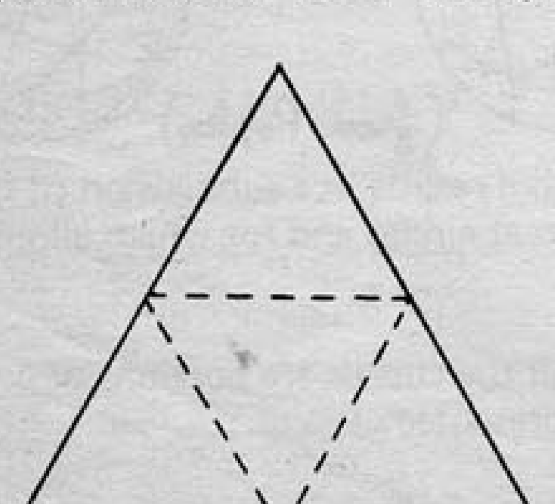



The angles of the right triangles formed at the vertices of the face are 36°; the spherical icosa has 5 faces at each vertex so 360/5 = 72° and the lines from the center of the face to the vertex bisect the 72° angle, 72°/2 = 36°.

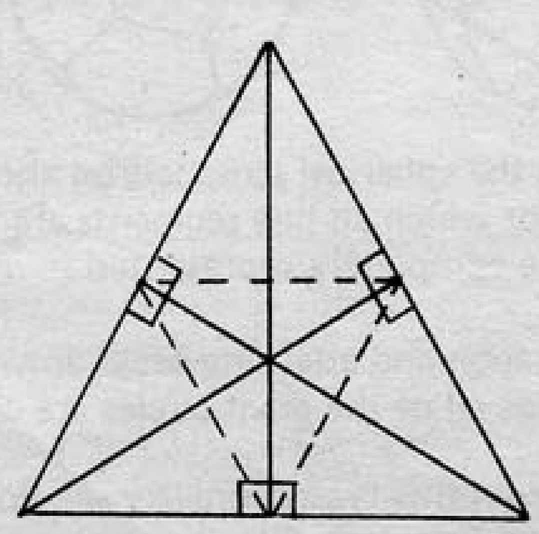



A great circle that bisects the edges of a spherical polyhedron is called an equator. An equator crosses the faces of a polyhedron equally. A great circle that bisects the edges of a spherical polyhedron and crosses the faces of the polyhedron equally is called an equator. The 6 and 10 great circles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

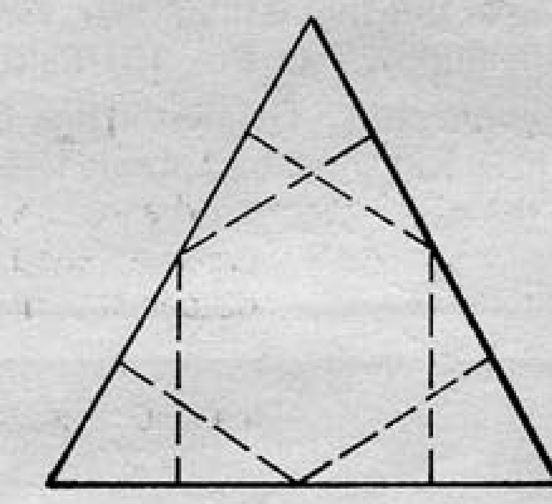


*The dotted lines (equators) are 1/10 the whole equator.*



*The section of the dotted lines (equators) 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.

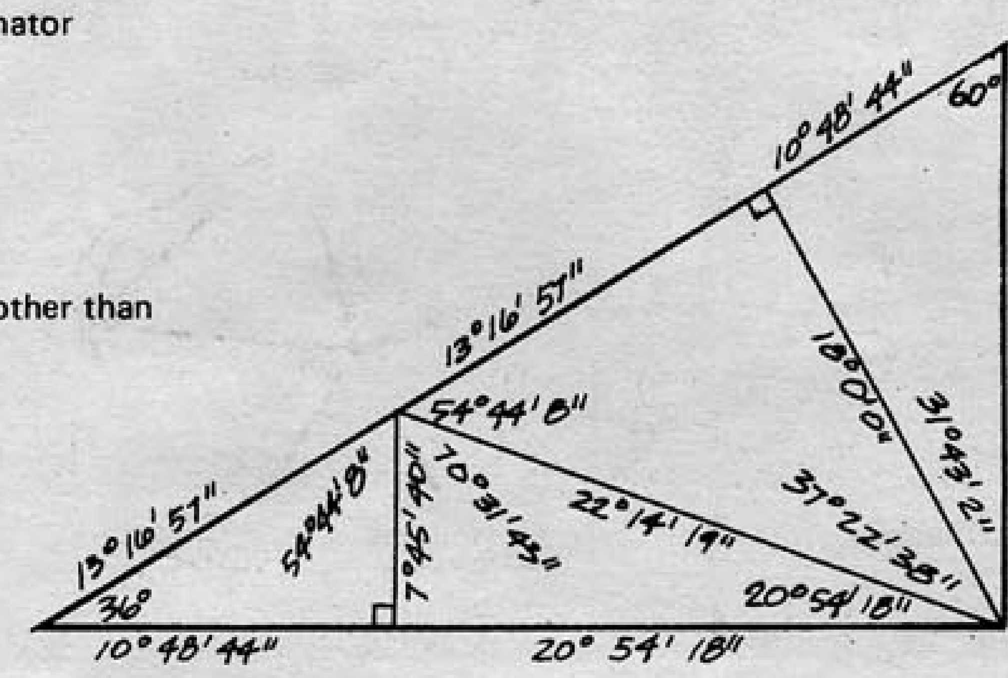
By more calculations (using spherical trig) you get the data for the 31 great circles. From that data you can get information for any frequency.

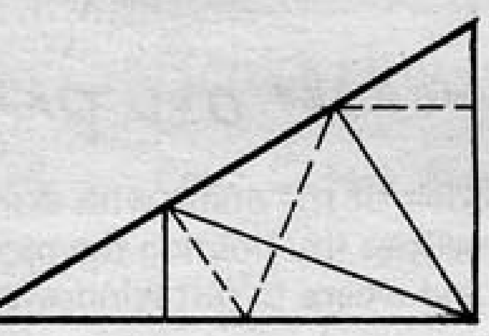
BASIC DATA 31 GREAT CIRCLES

in lowest common denominator of a sphere's surface

3 different external edges
3 different internal edges

6 different internal angles other than 90° or 60°

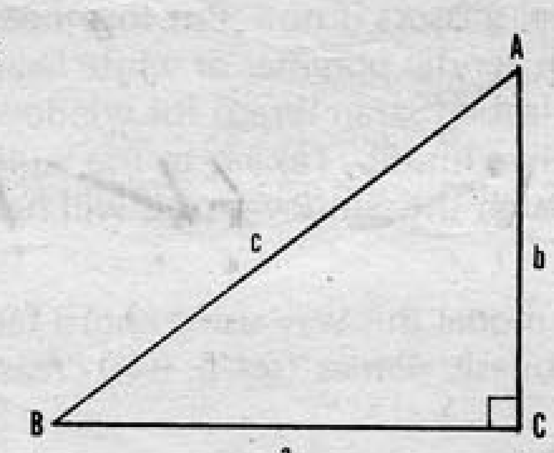


solid lines 31 great circles,
dotted lines superimposed
Fuller 4v alternate.
See Clinton's Class I, Method 3

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

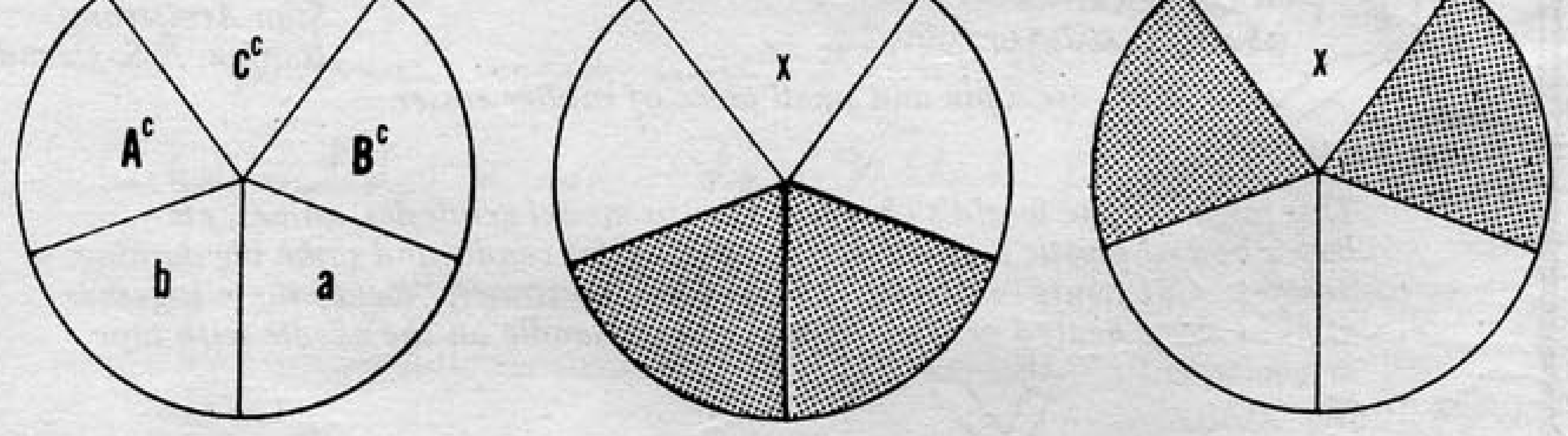
To identify sides and angles:




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.



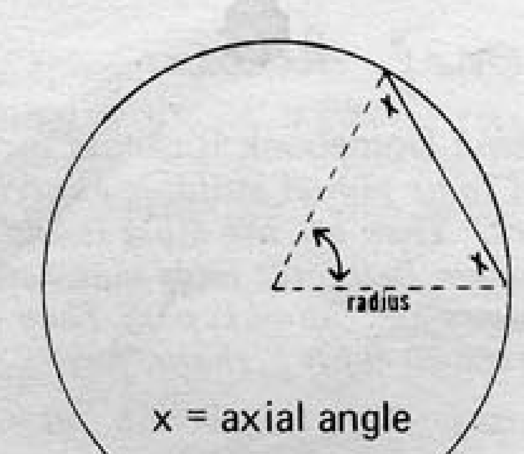

opposite case

adjacent case

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

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

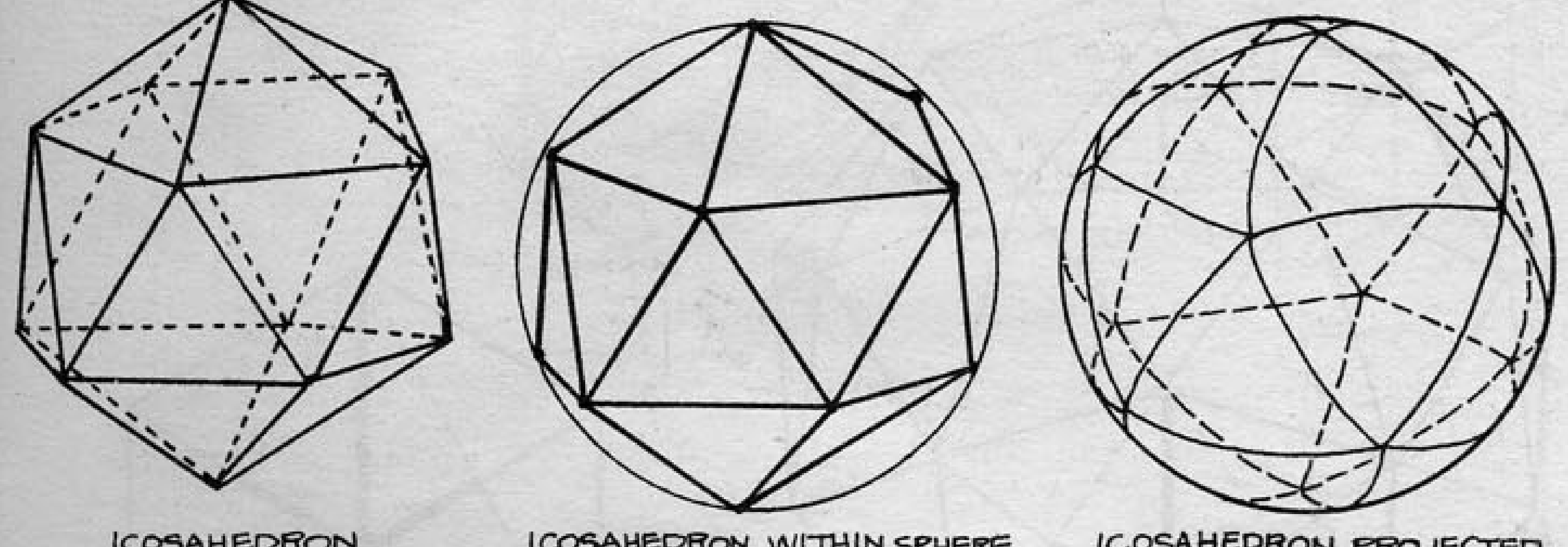
Jonathan Kanter

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 triacon 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 connectors. 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 VERTEXES TOUCH SPHERE* | ICOSAHEDRON PROJECTED ONTO SPHERE

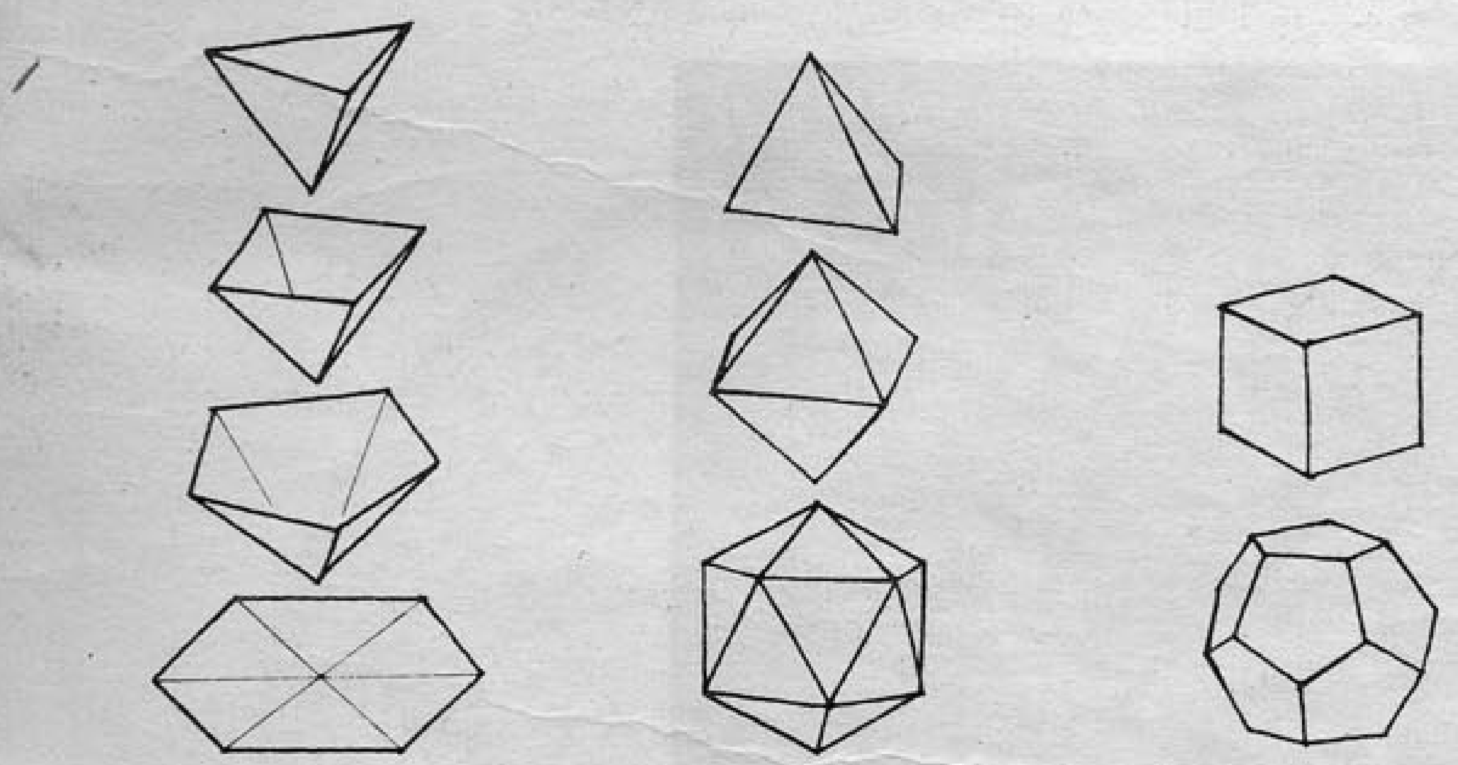
Two breakdowns are possible when: the face is subdivided into triangles and the symmetry of the equilateral triangle face is retained. They are the alternate and triacon. This is a general geometrical explanation.

There are different sets of chord factors within the basic geometry. Clinton derives his from the coordinates of vertices on the sphere and uses analytical geometry. See Geodesic Math, p. 106 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).

## PLATONIC SOLIDS

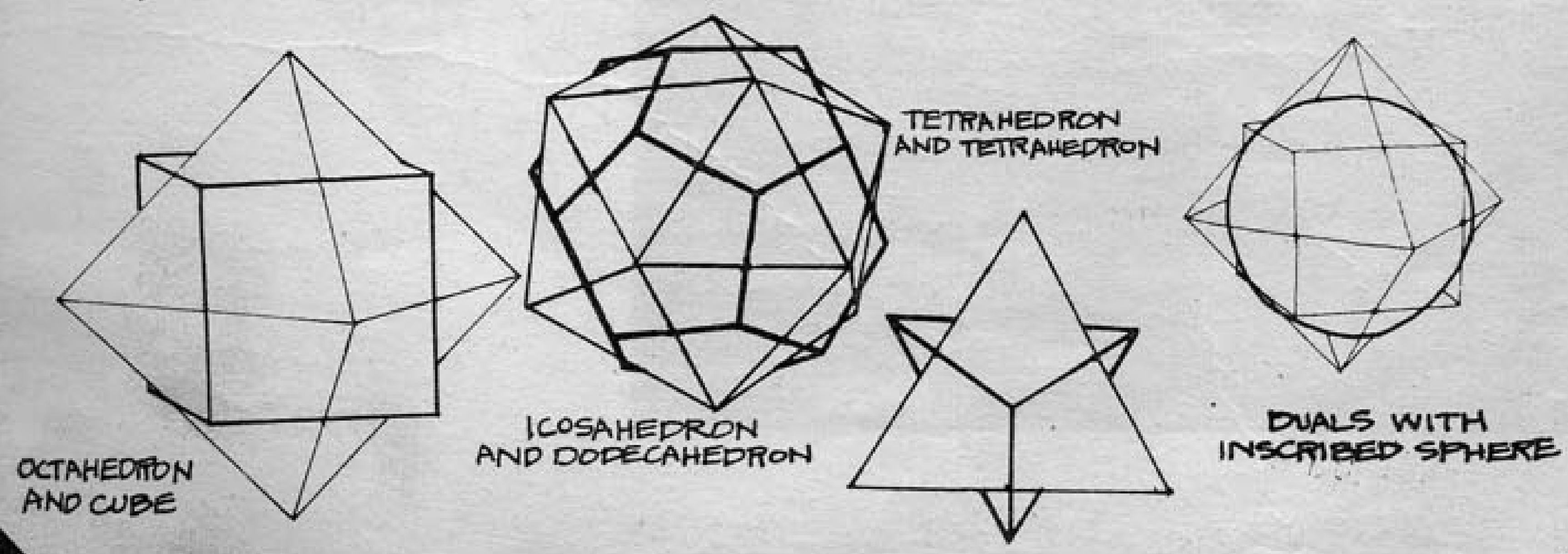
The platonic solids are the most basic structures known. The cube is the most commonly used of these solids as an archetype for construction. The structures in this book represent an attempt to reexamine these basic solids and to find different channels and foundations for new forms of construction.

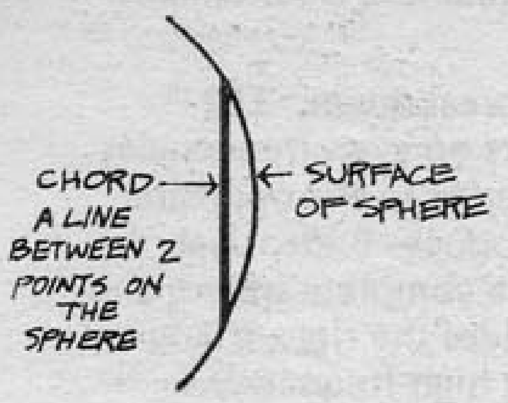
The platonic solids are defined as having equal faces (regular polygons), equal vertices, and equal dihedral angles between the faces. To generate the solids from equilateral polygons there are only 3 polygons which will fit together in three dimensional (3-d) space: the equilateral triangle, the square, 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).

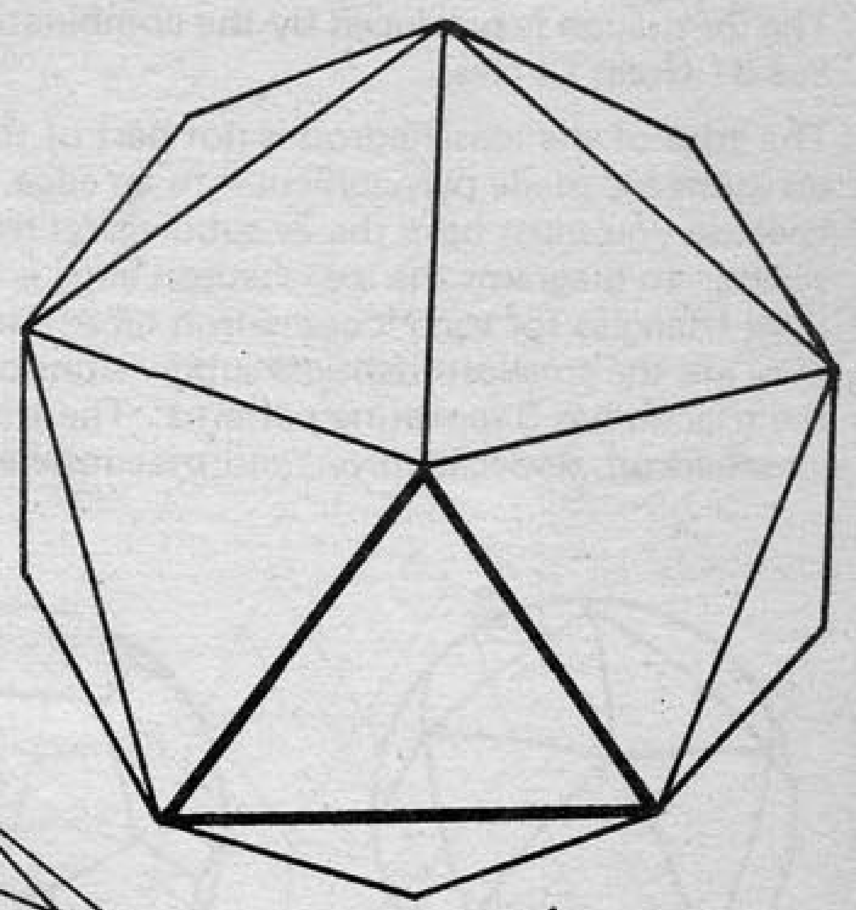


Squares and pentagons will fit together in threes at each vertex; this produces the cube and the dodecahedron.

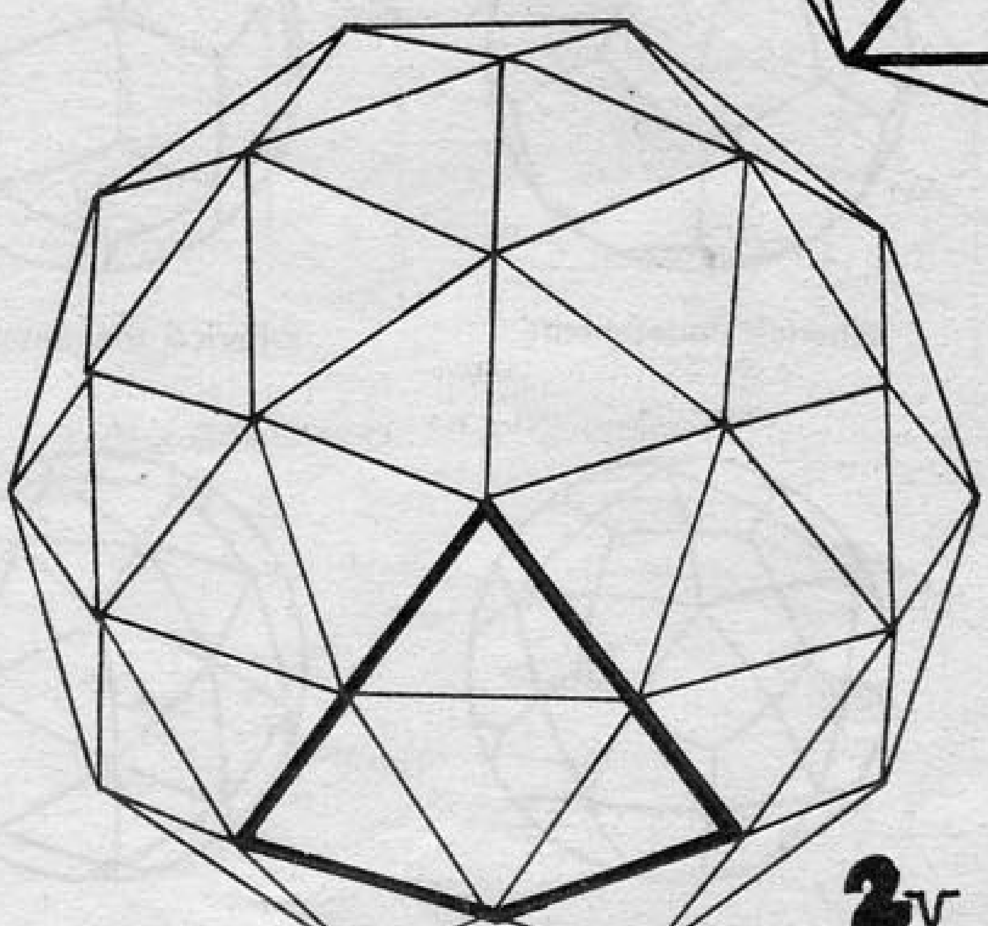
Two solids are considered to be duals if the number of vertices of one equals the number of faces of the other and they have an equal number of edges. The dual of a solid can be generated by inscribing a sphere so that it is tangent to the solid at the midpoints of its edges and then by drawing lines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



1ν



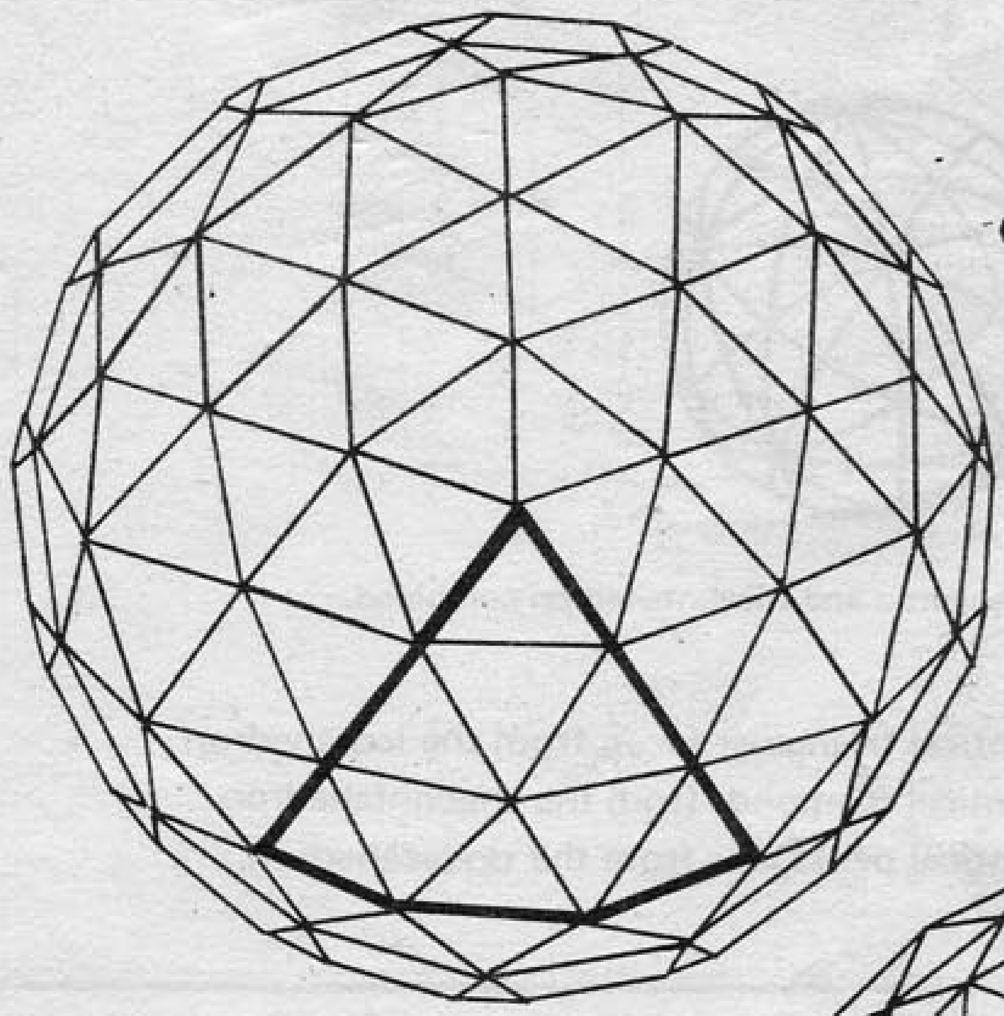
2ν

## ALTERNATE BREAKDOWN

• VERTEX UP •

ONE ICOSA FACE IS OUTLINED

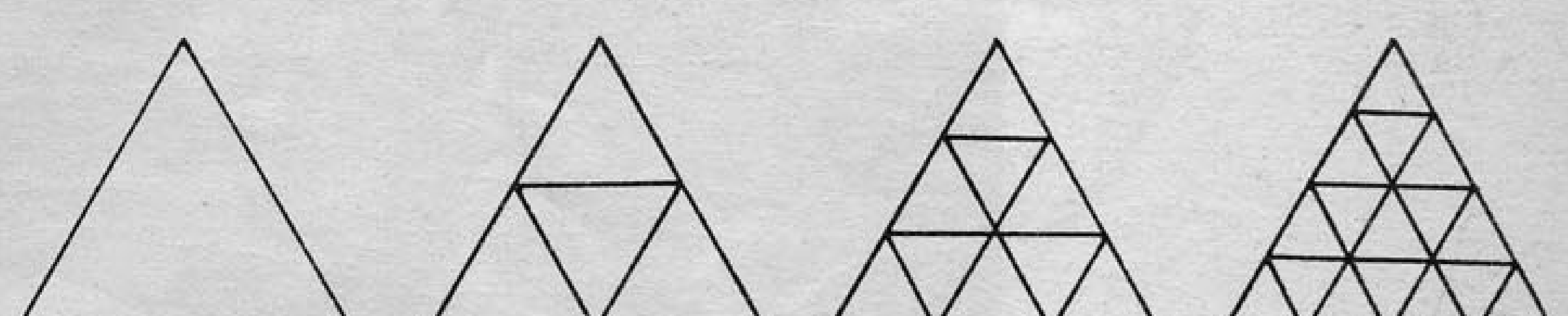
*CHECK SIMPLE GEODESICS*



3ν

4ν

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.




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, ν = frequency

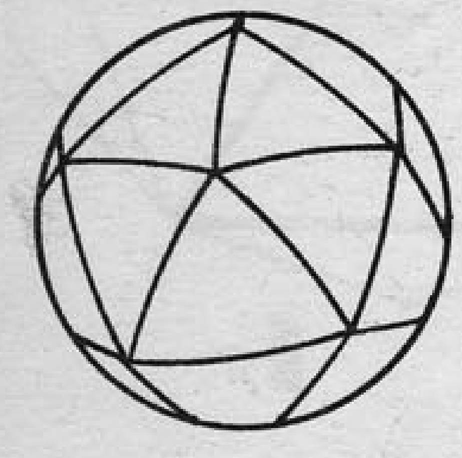
GEODESIC GEOMETRY

# TRIACON

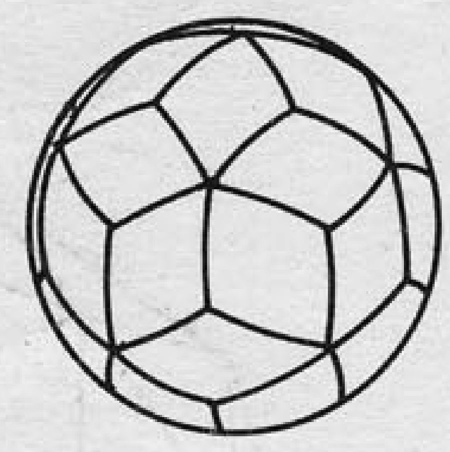
## BREAKDOWN
·VERTEX UP·

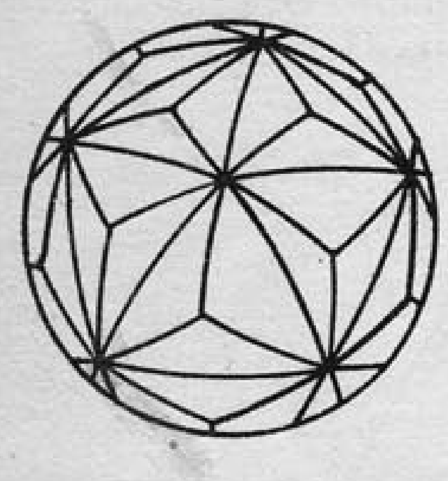
The 2v triacon is produced by the combination of the dodecahedron, and triacontahedron. See 31 Great Circles.

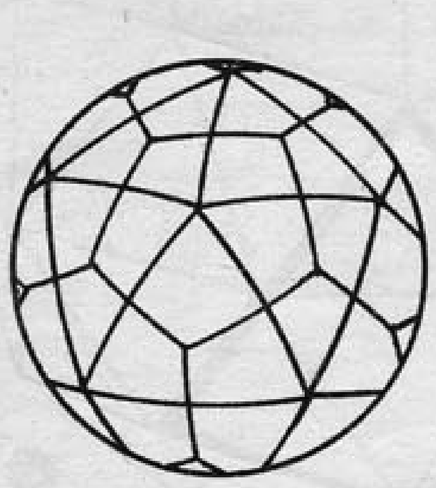
The edge of the icosahedron is not part of the dome in the triacon breakdown. The divisions are made perpendicular to an edge. The triacon only works on even frequencies because you must have the 2v subdivision from the middle of each edge to the opposite vertex. In diagrams the icosahedron edge is dotted. 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.

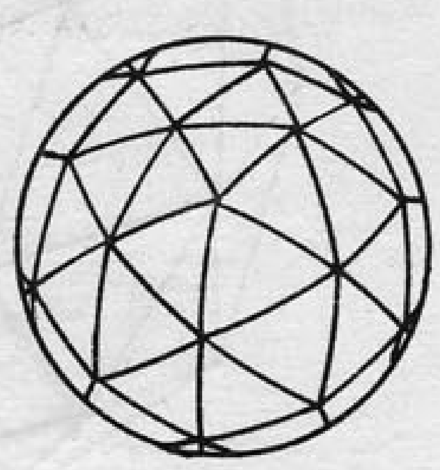

spherical icosahedron

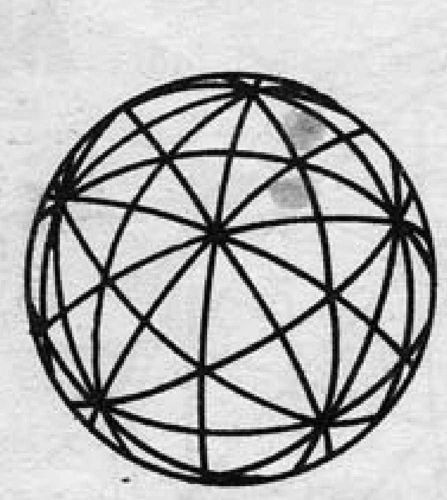

spherical dodecahedron


spherical triacontahedron

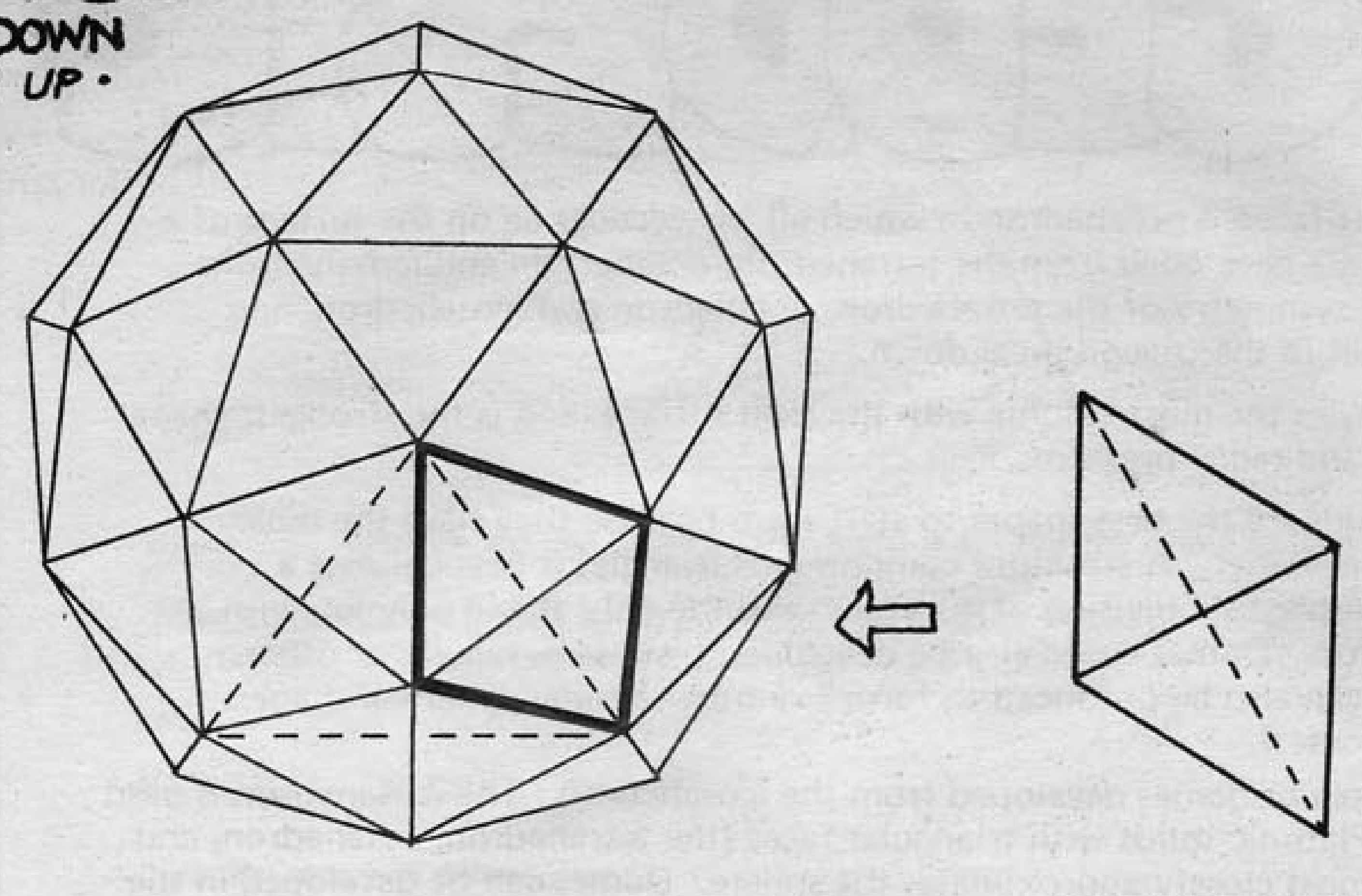

spherical icosahedron and triacontahedron combined

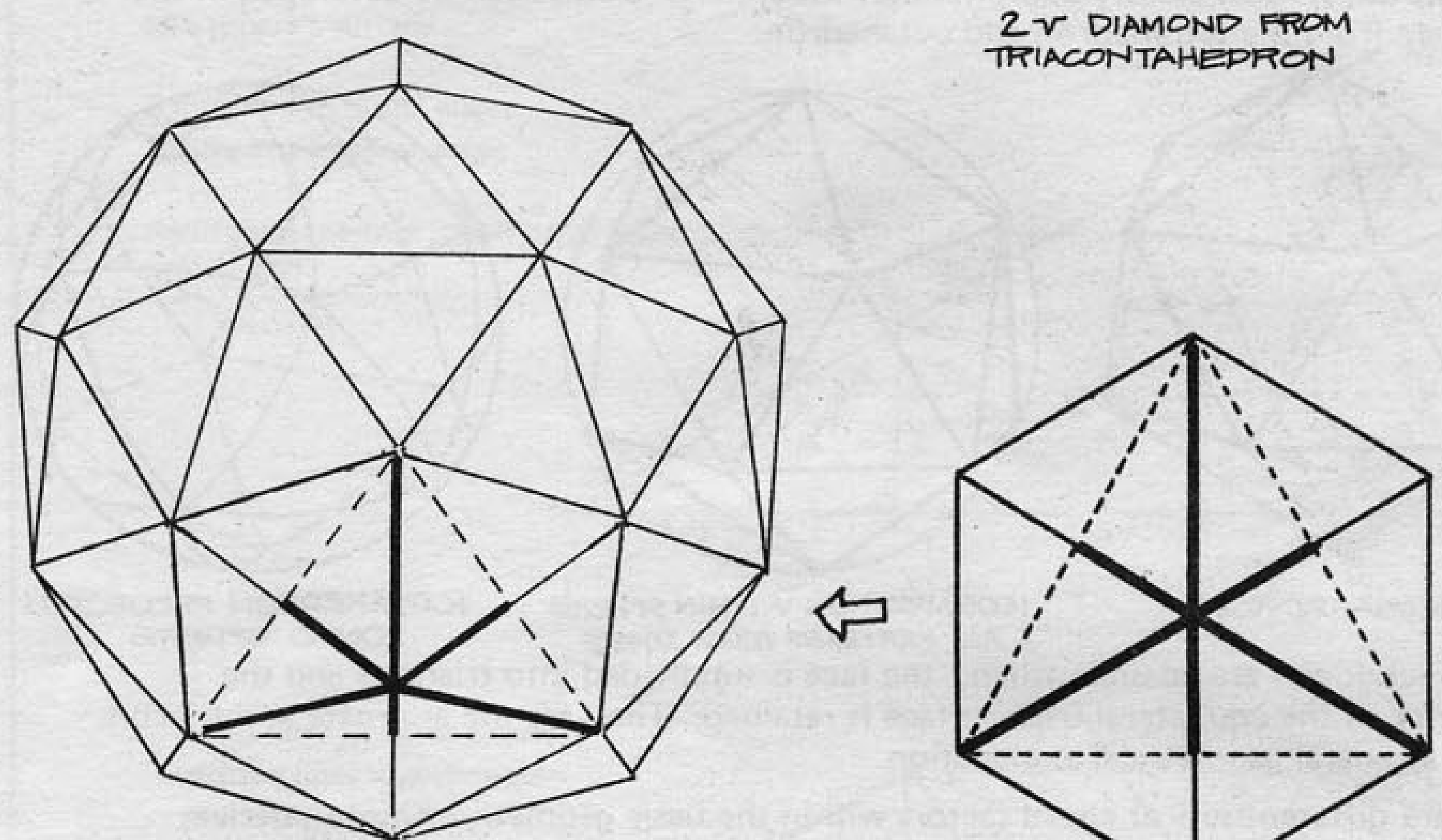

spherical icosahedron and dodecahedron combined

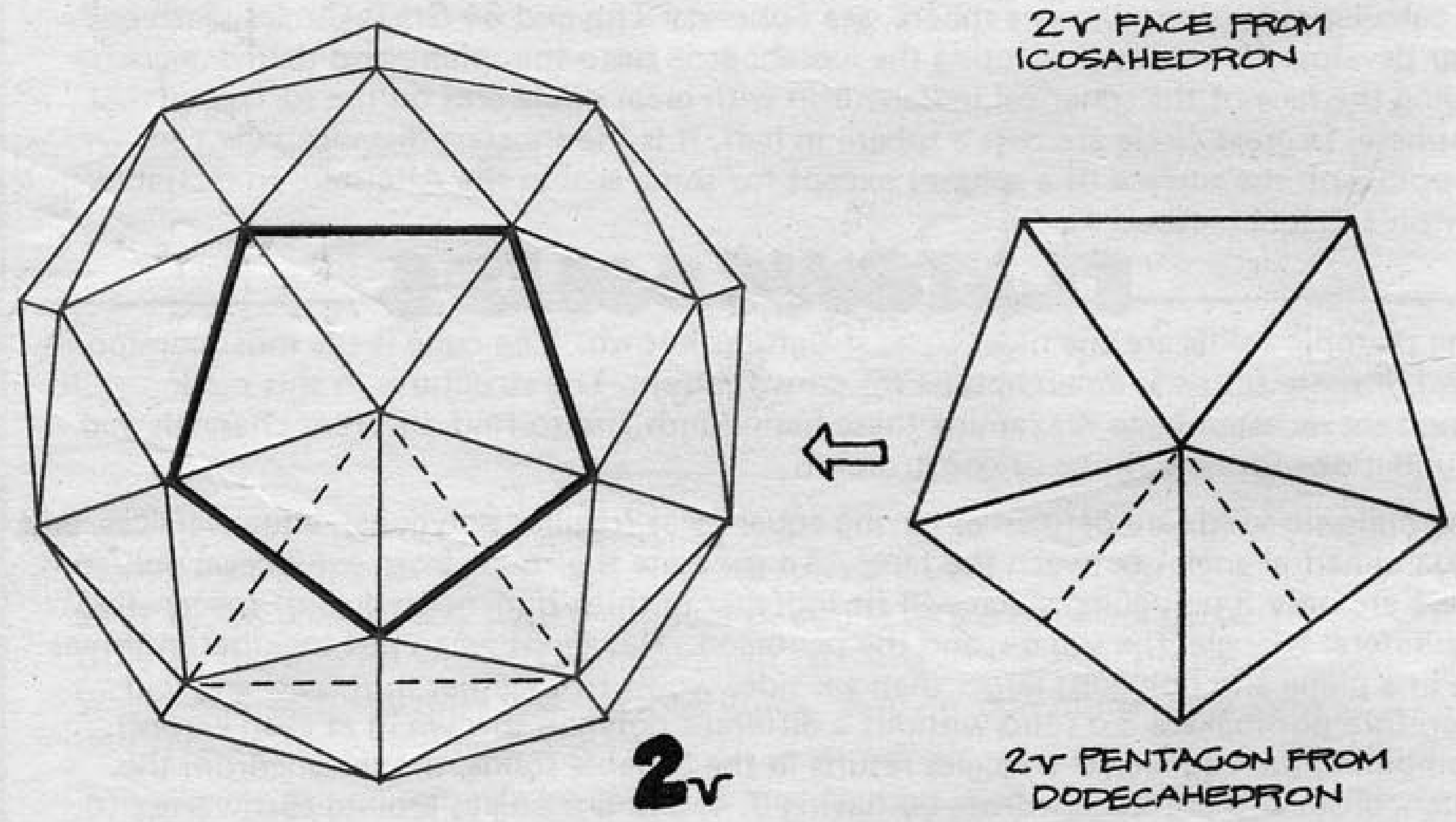

spherical dodecahedron and triacontahedron combined


Spherical icosahedron, dodecahedron and triacontahedron combined.

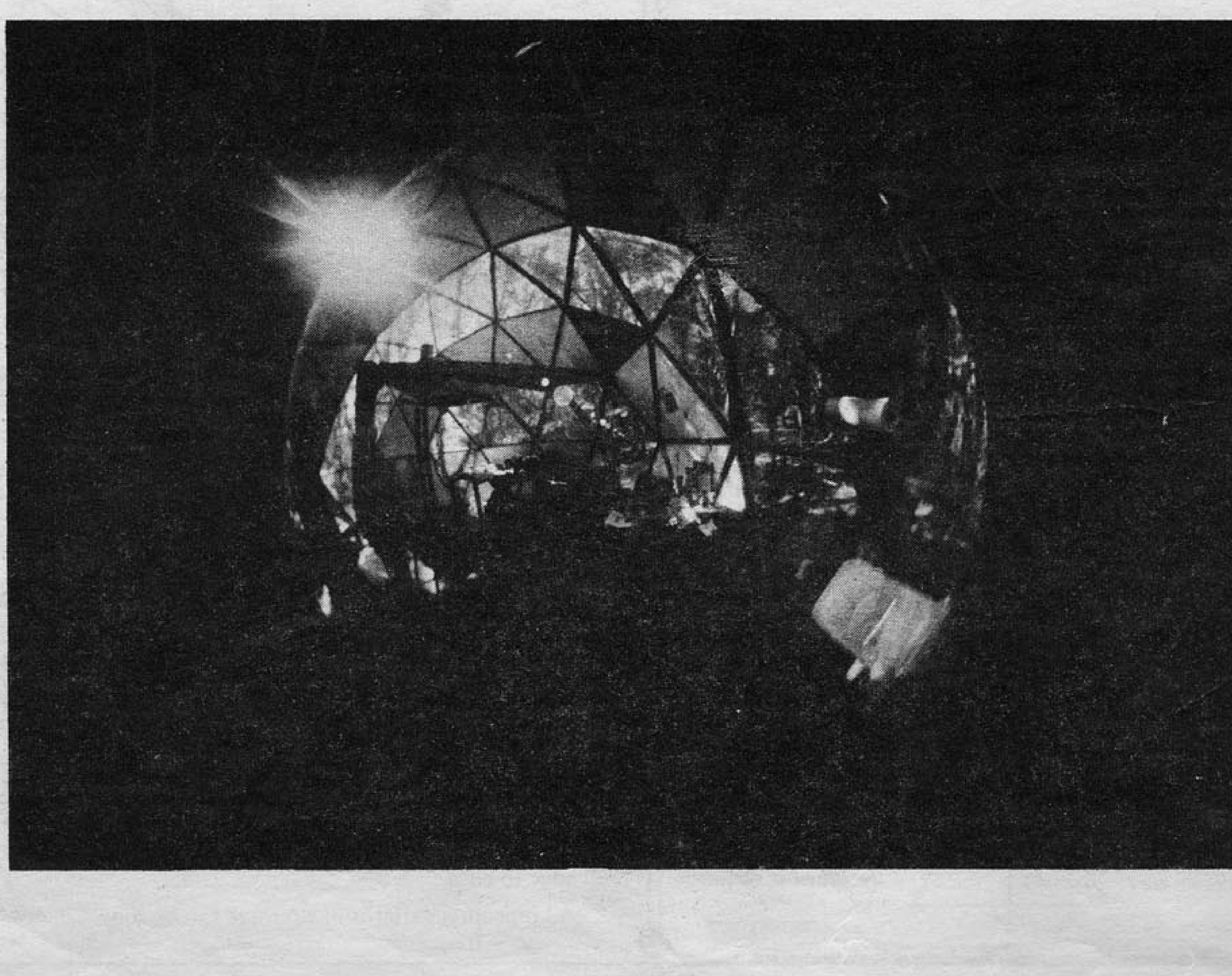
Every triacon breakdown has:
- 20 identical triangular faces, from the icosahedron
- 30 identical diamonds from the triacontahedron
- 12 identical pentagons from the dodecahedron.


2v DIAMOND FROM TRIACONTAHEDRON

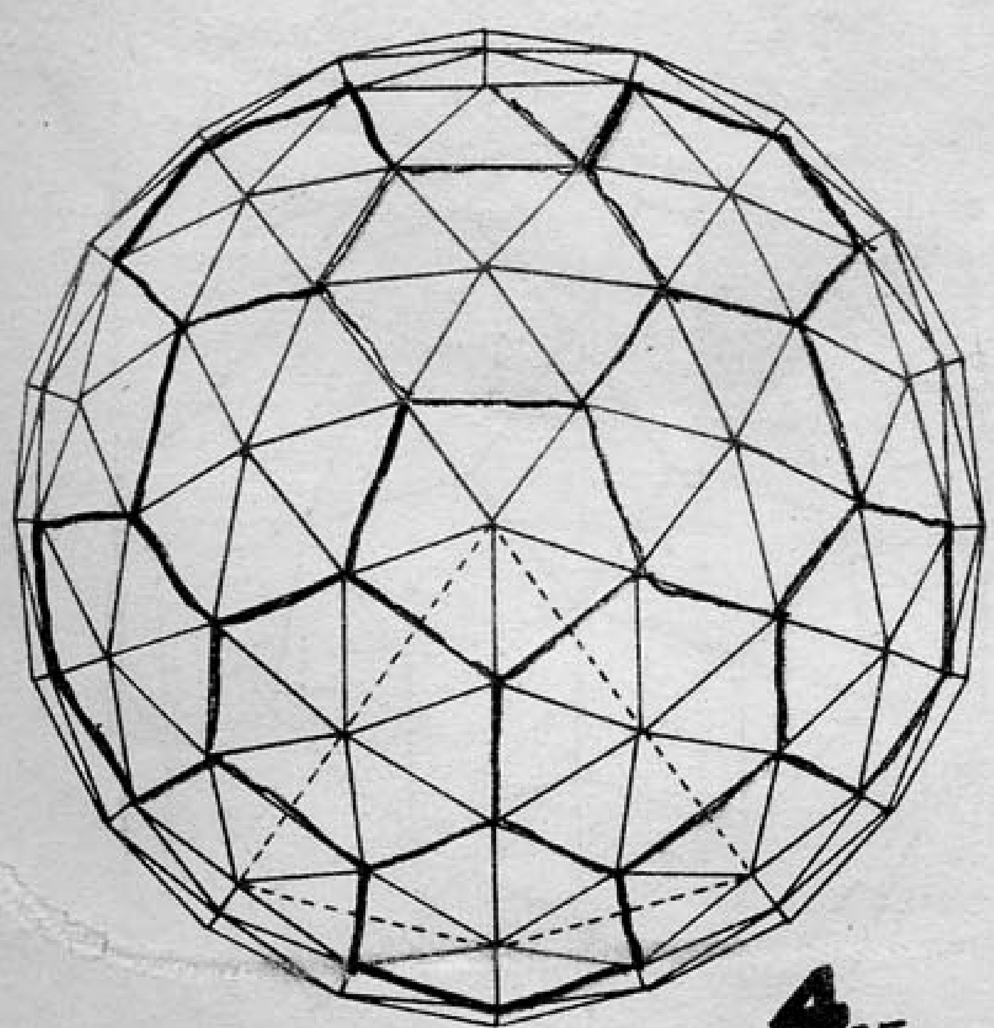

2v FACE FROM ICOSAHEDRON



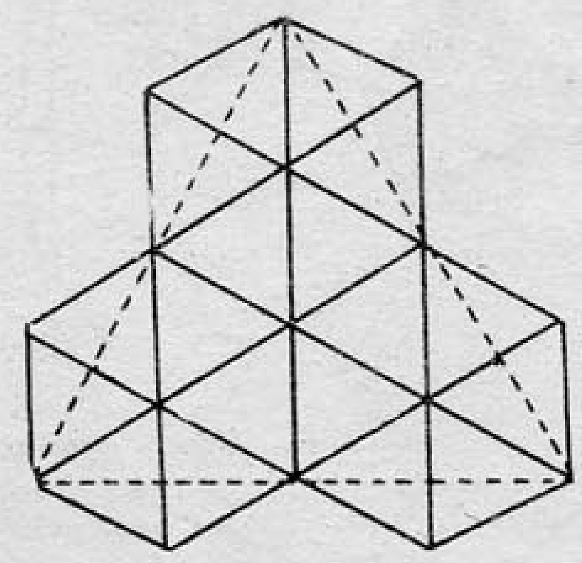
2v PENTAGON FROM DODECAHEDRON



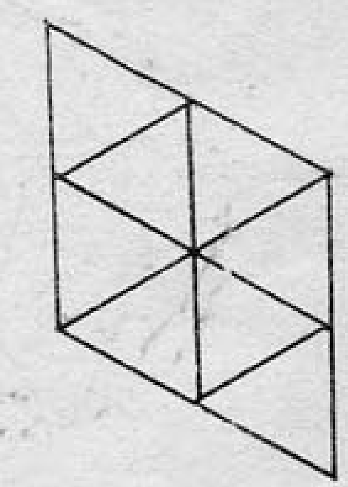
# MORE... TRIACON BREAKDOWN
### · VERTEX UP ·



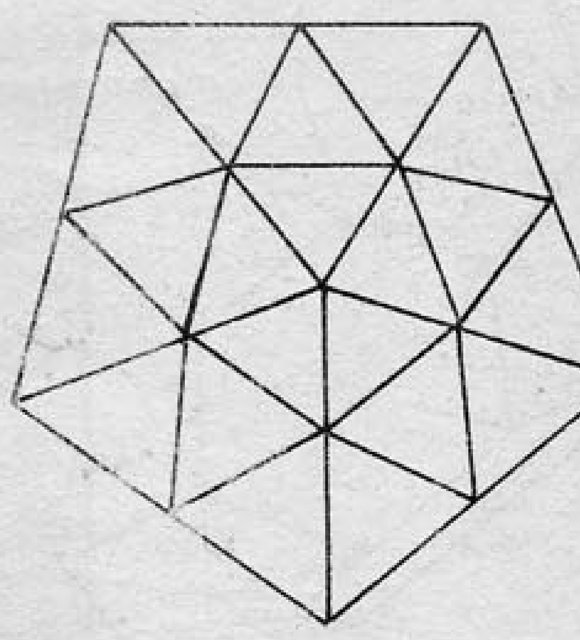
4v



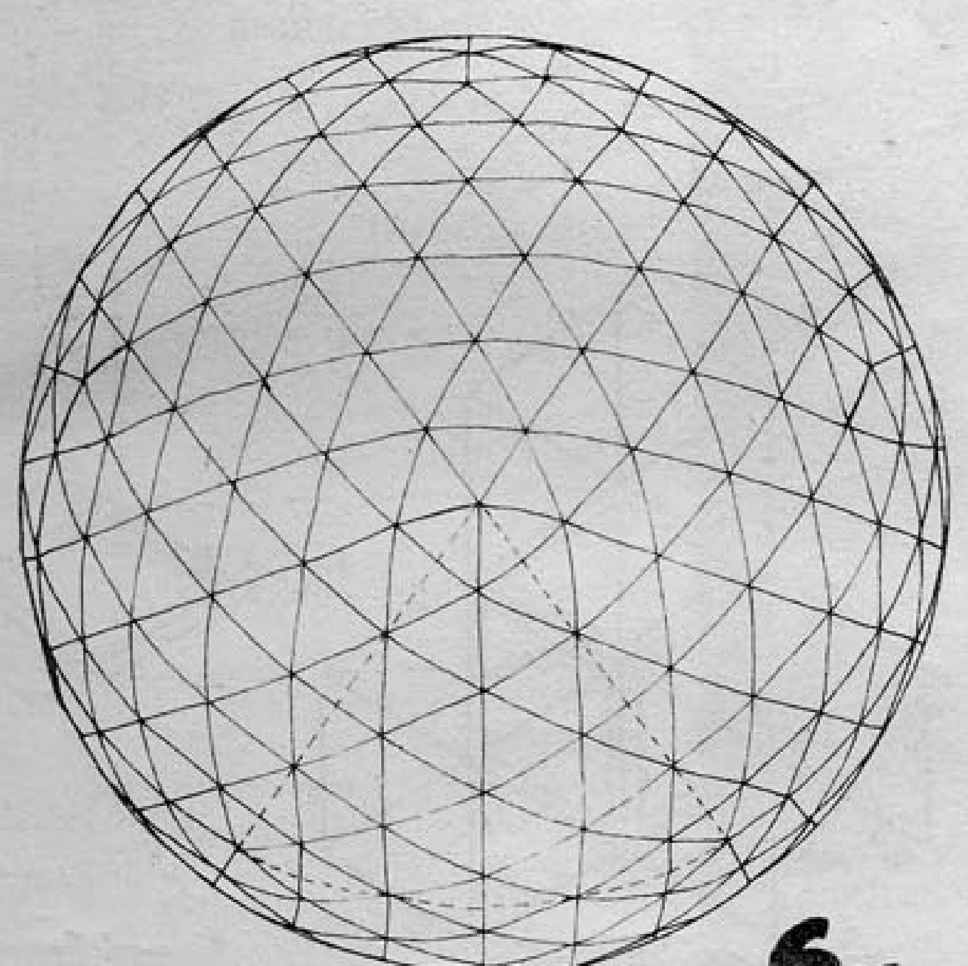
4v FACE



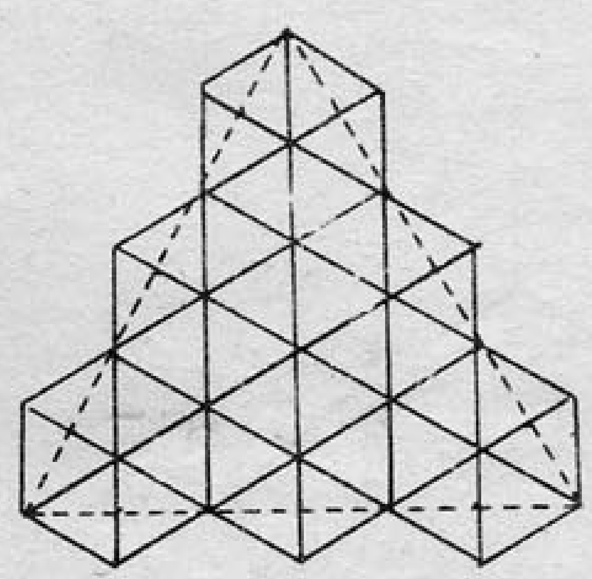
4v DIAMOND



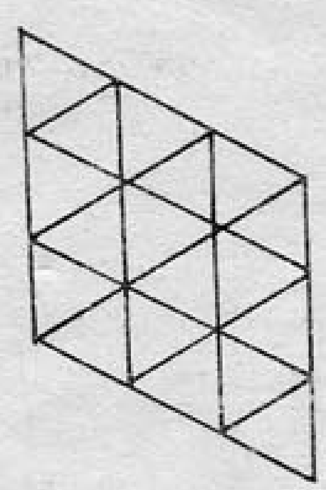
4v PENTAGON



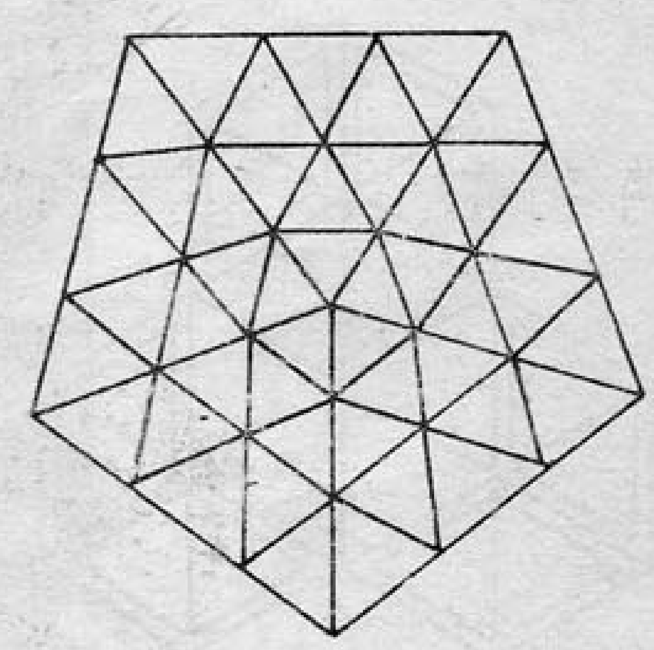
6v



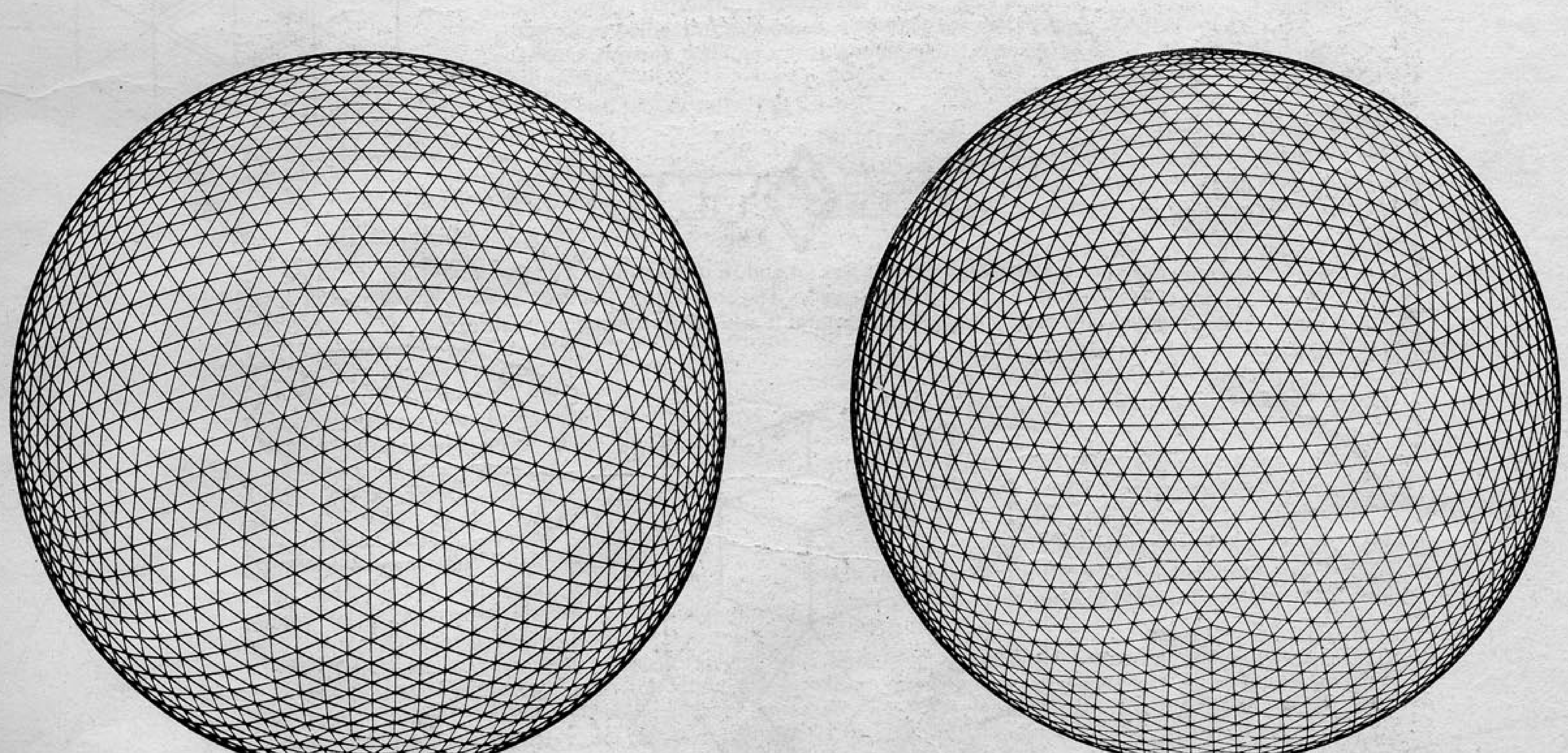
6v FACE



6v DIAMOND



6v PENTAGON

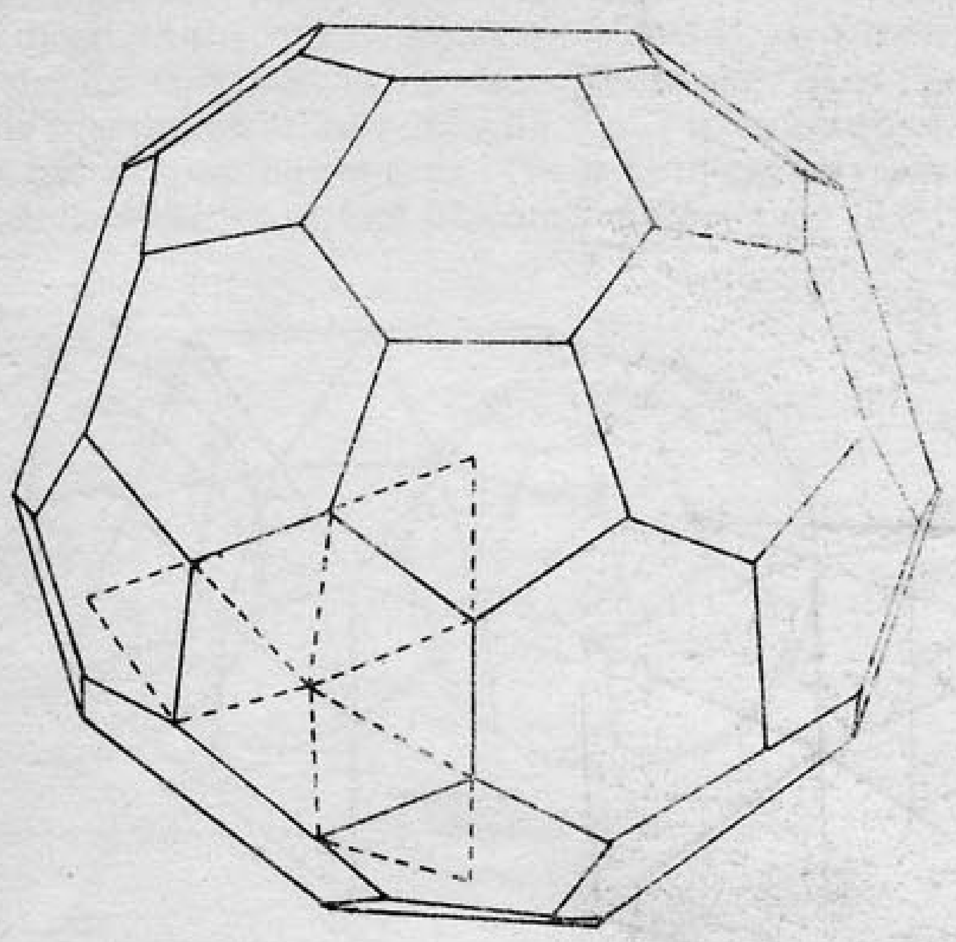


*16 frequency alternate spheres*
*computer graphics from program by Joe Clinton*

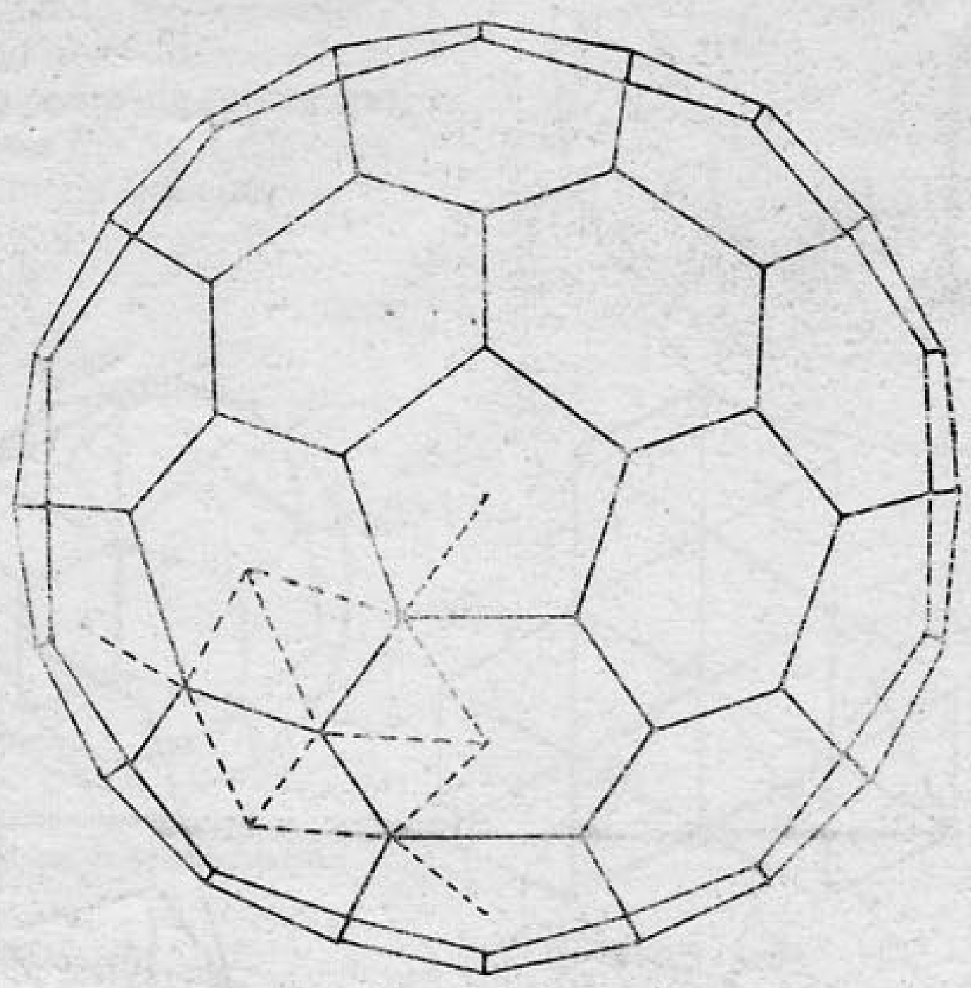
# MODIFIED SPHERES

You can easily modify or distort domes. Besides domes with completely different shapes (see Elliptical Domes) you can just change the length of, or remove, or replace with cable some struts. The struts inside the hexagons and pentagons can be removed making flat hexagons and pentagons. The strut lengths and angles are the same as with all triangles. When removing struts to form hexagons and pentagons you need to use a frequency with a point in the center of the face (so for triacon any frequency works).

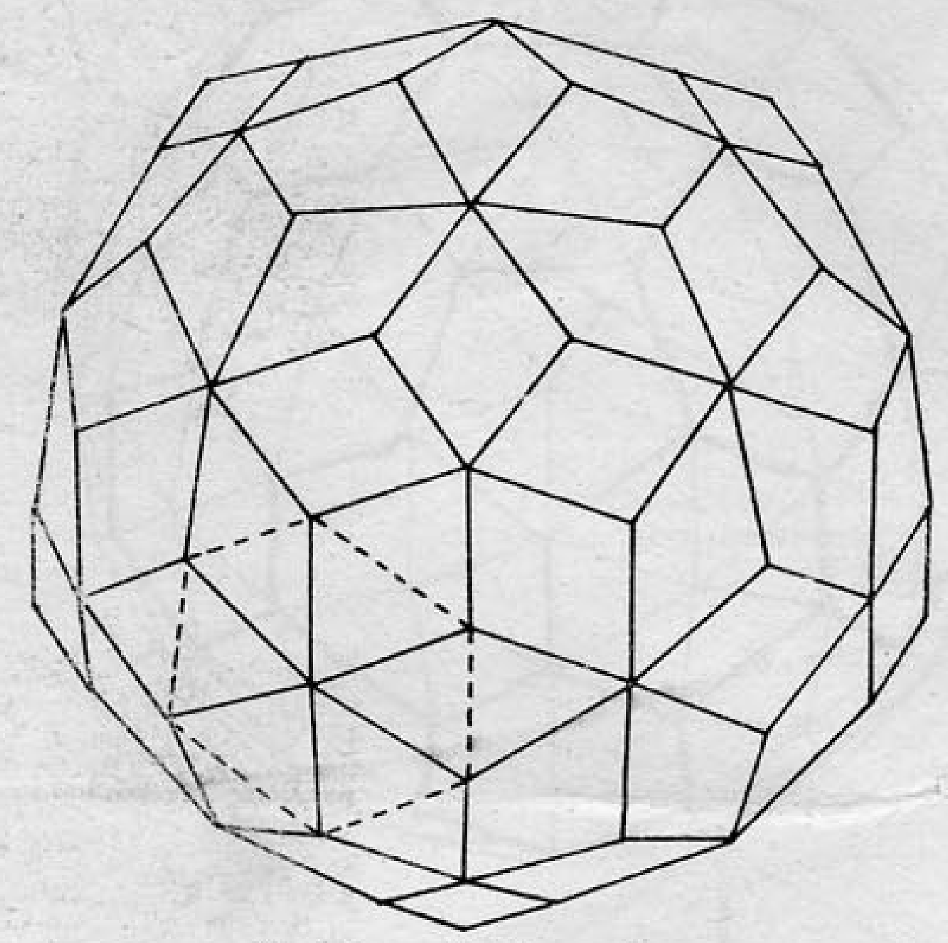
Or two triangles can be grouped together to form diamonds. The strut lengths and angles are the same as with all triangles. With alternate there must be at least $3^v$ and the pattern is symmetrical only with a point in the center of the icosahedron face. With triacon any frequency works. The diamonds are bent along their short axis.



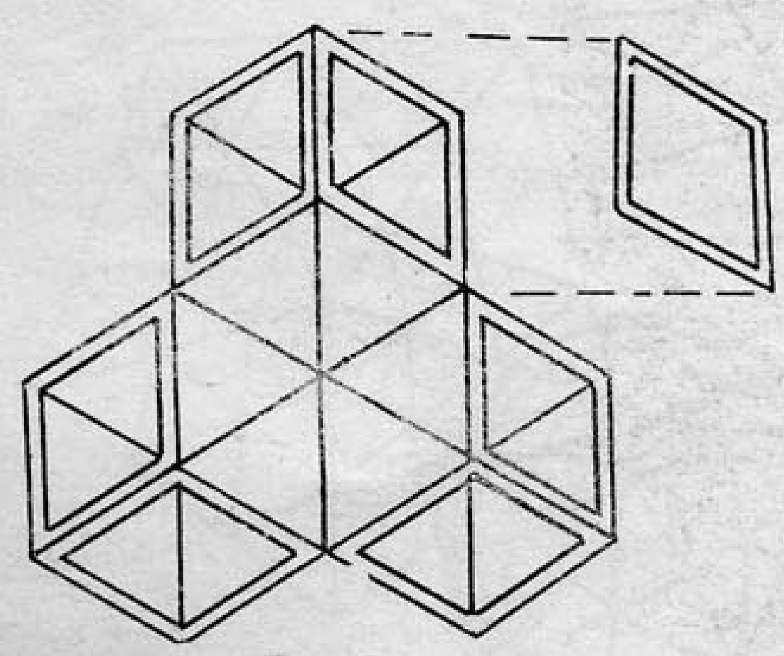
*Top view of $3_v$ icosa alternate. Removed struts from one face dotted.*



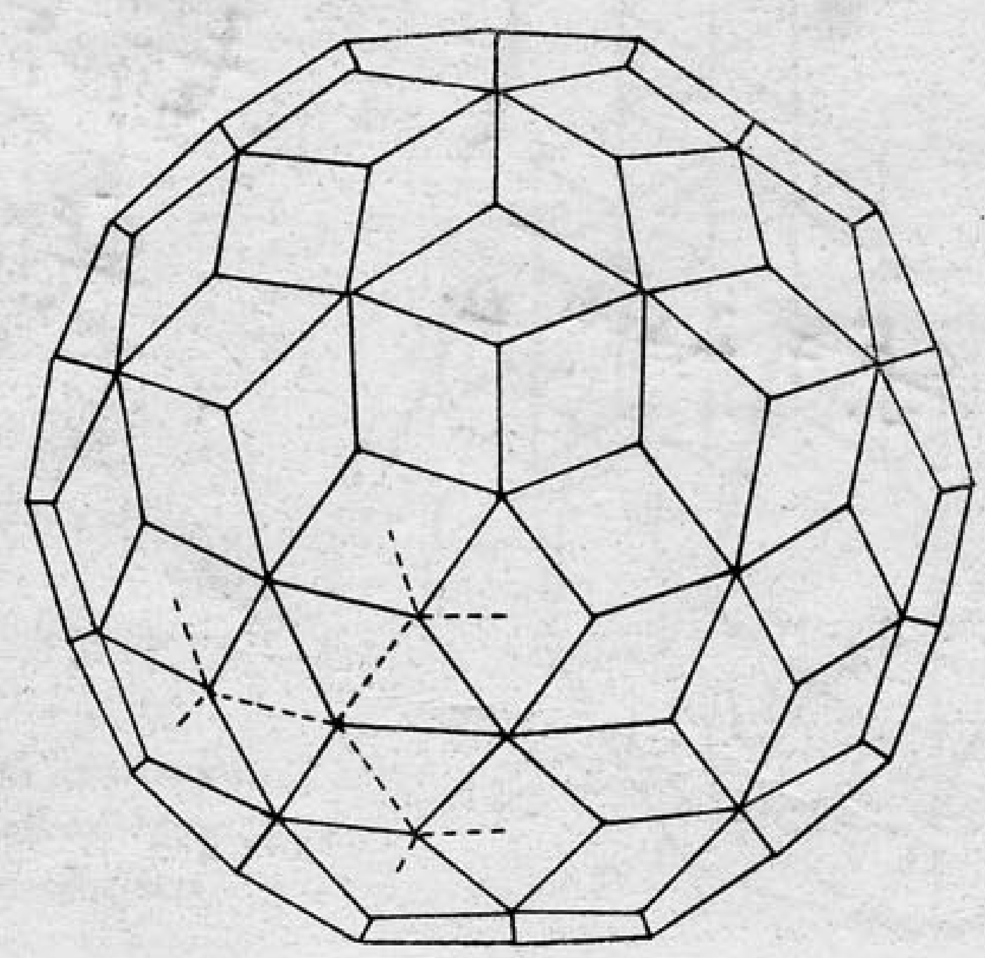
*Top view of $4_v$ icosa triacon. Removed struts from one face dotted*



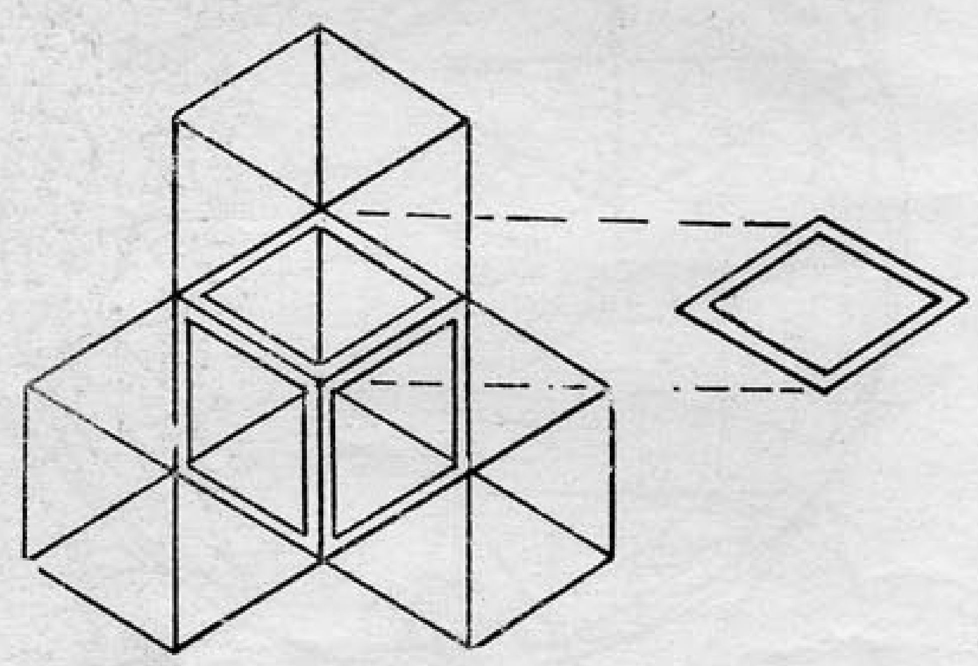
*Top view of $3_v$ icosa alternate. Removed struts from one face dotted.*



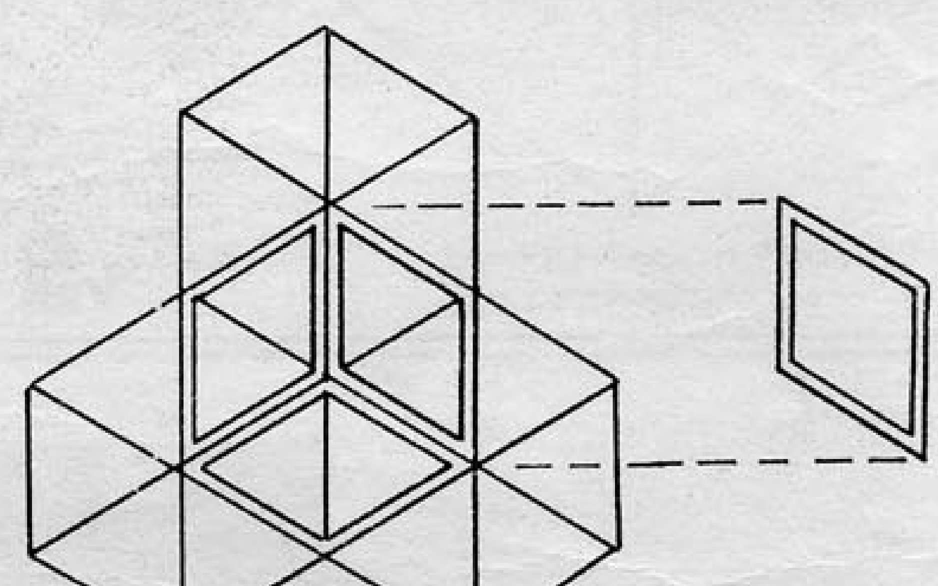
For $4_v$ triacon you use this diamond



*Top view of $4_v$ icosa triacon (with diamond Removed struts from one face dotted.*



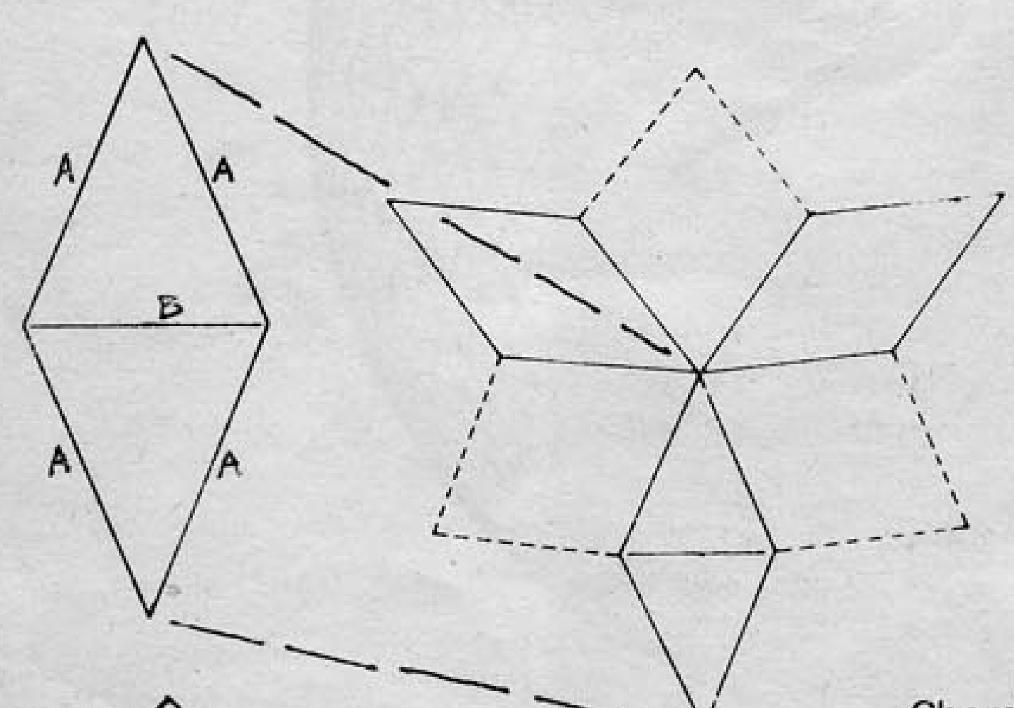
and this diamond



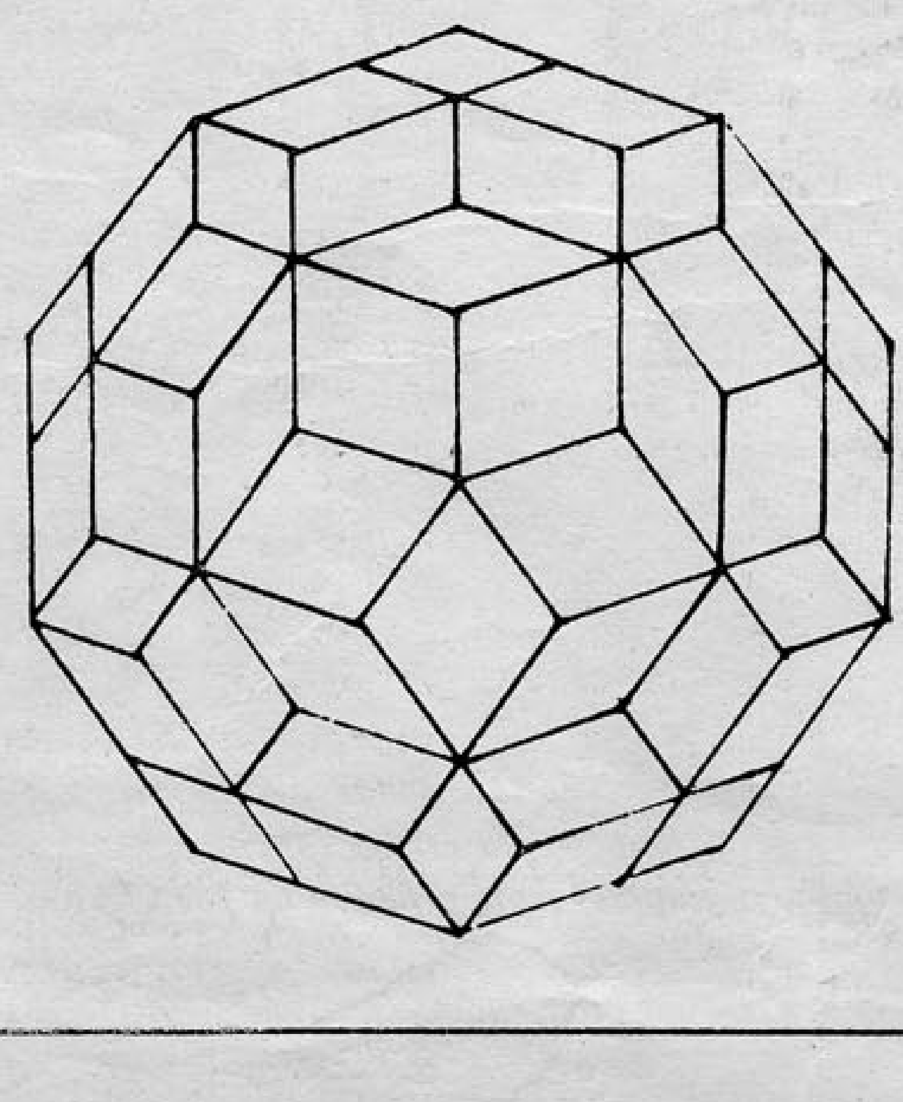
or this diamond

## FAT ◇ THIN

Another breakdown produces flat fat and thin diamonds. The diamonds have the same edge length but different face angles. The angles opposite each other in the diamonds are equal. The fat diamond/thin diamond is also called the enenicontahedron.

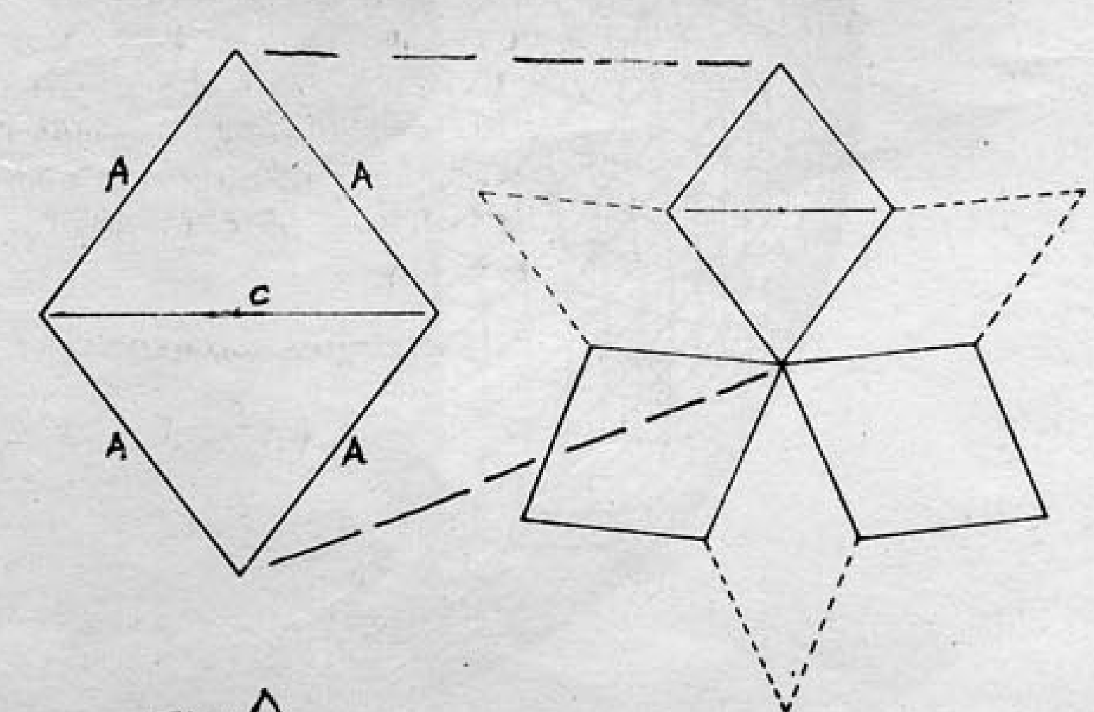



THIN ◇

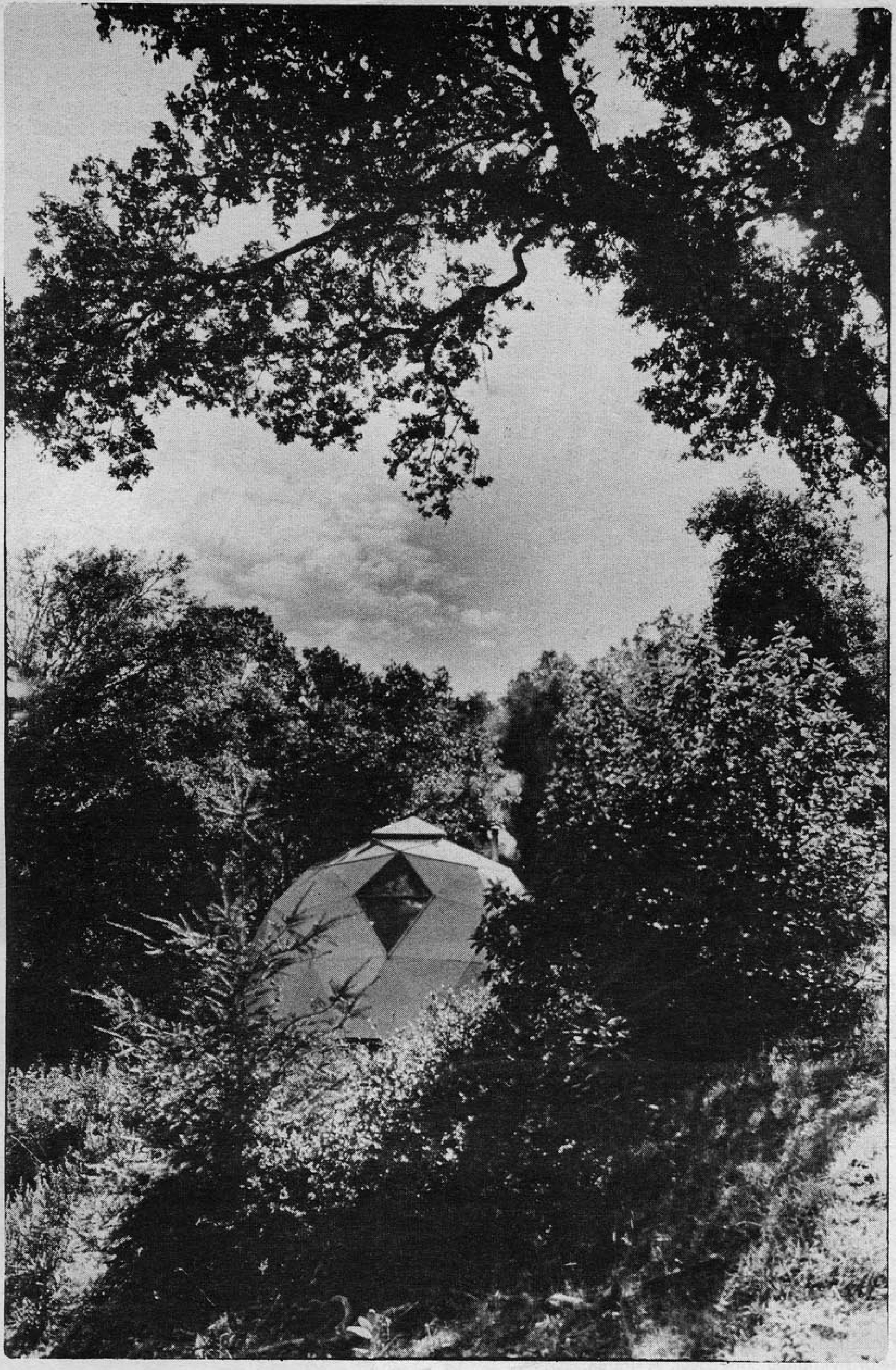


Chord Factors:

A .3932
B .3137
C .4534




FAT ◇



*"All is as it should be," says one of the beings.*

*"Nothing is complete," returns the other; "look at those creatures below this mountain, whom we see assembling, then disbursing, looking about, and betaking themselves to shelter."*

Building is a time of expansion.

Writing about it is a contracting, a gathering in, putting years of work by many people into a book like this.

There's even an analogy between building/communicating and framing/skinning a dome. Putting up the framework is exciting, moving, joyous; putting on the skin is difficult and meticulous.

It's much easier to build than it is to write about it, perhaps that's why so little has been written on building. Most books and magazines on building don't cover shelter, but rather monumental works by a few master architects and their patron-inspired design. However, for thousands of years, men have been building beautiful shelters, using indigenous materials, inspired by the architecture of necessity.

As we've built and experimented with domes over the past few years, we've tried to keep notes, so that we'd be able to pass along what we've learned. However, we've been rushed, in both building and writing; urgency has been a prime mover in our actions, rather than fine craftsmanship and design, as we were literally throwing up shelters to beat oncoming rains. Thus you should not use any of these instructions as step-by-step procedure, but rather design and build your own shelter. You should be able to pick up where we left off, and avoid many of our mistakes.

Pacific High School provided the testing ground for many of these domes. Some were built prior to our first publication, *Domebook One,* others from it.

No plans were ever drawn for our domes, only a few sketches. Our blueprints have been mathematics. As you read the rest of the book, it may be helpful for you to know of the following general categories of dome construction:

*Sun Domes.* The Sun Dome was a swimming pool cover dome published by Fuller through *Popular Science* in 1966. For some time, this was the only geodesic geometry available to anyone wanting to build a dome. The Sun Dome is made of triangles on frames that bolt together to make the dome. Some examples are Sun Dome, p. 14; Big Sur Dome, p. 16; Aluminum Sun Dome, p. 29.

*Struts/skin domes.* First the framework is put up, usually with various vertex connectors, then a skin applied. See Pacific Dome, p. 20.

*Flanged panel dome.* Skin and struts are one-piece, with skin flanged over to form strut. Assembly is like the Sun Dome, usually with bolts, or rivets. Example: Aluminum Triacon Dome, p. 26.

*Monolithic skin domes.* Dome skin is applied in liquid form, hardens to make a one-piece rigid skin. See Egg Domes, P. 35; Muslin Foam Dome, p. 40; Ferro Cement Dome, p. 66.

*Tent Domes.* A one-piece skin is either hung from, or draped over a frame. See Tent Domes, p. 48.

The first section of the book was mathematics. What follows are our building and living experiences, and communication from other builders throughout the U. S. and Canada.

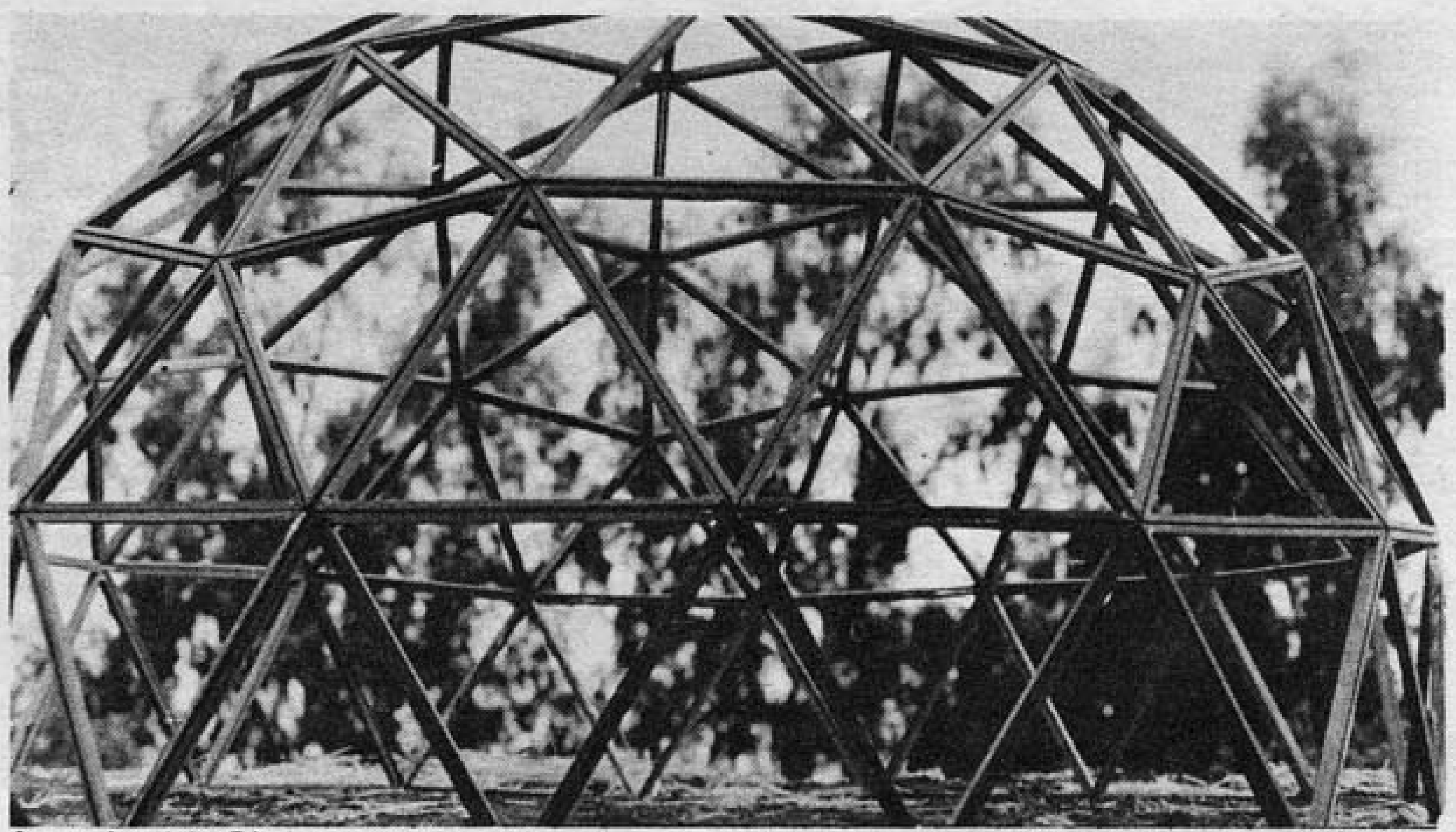
# Sun Dome

The sun dome is a logical next step after model making; it's like making a full scale model. It is cheap, lightweight and easy to build. It is a panel frame system, with triangles preassembled in the shop, then fastened together to make the structure. After building the models and small dome described below, I next built the full size dome in Big Sur, which is the same basic system, with plywood instead of plastic skin. Two years later we built the Aluminum Sun Dome (see p. 29), this time with aluminum skin.

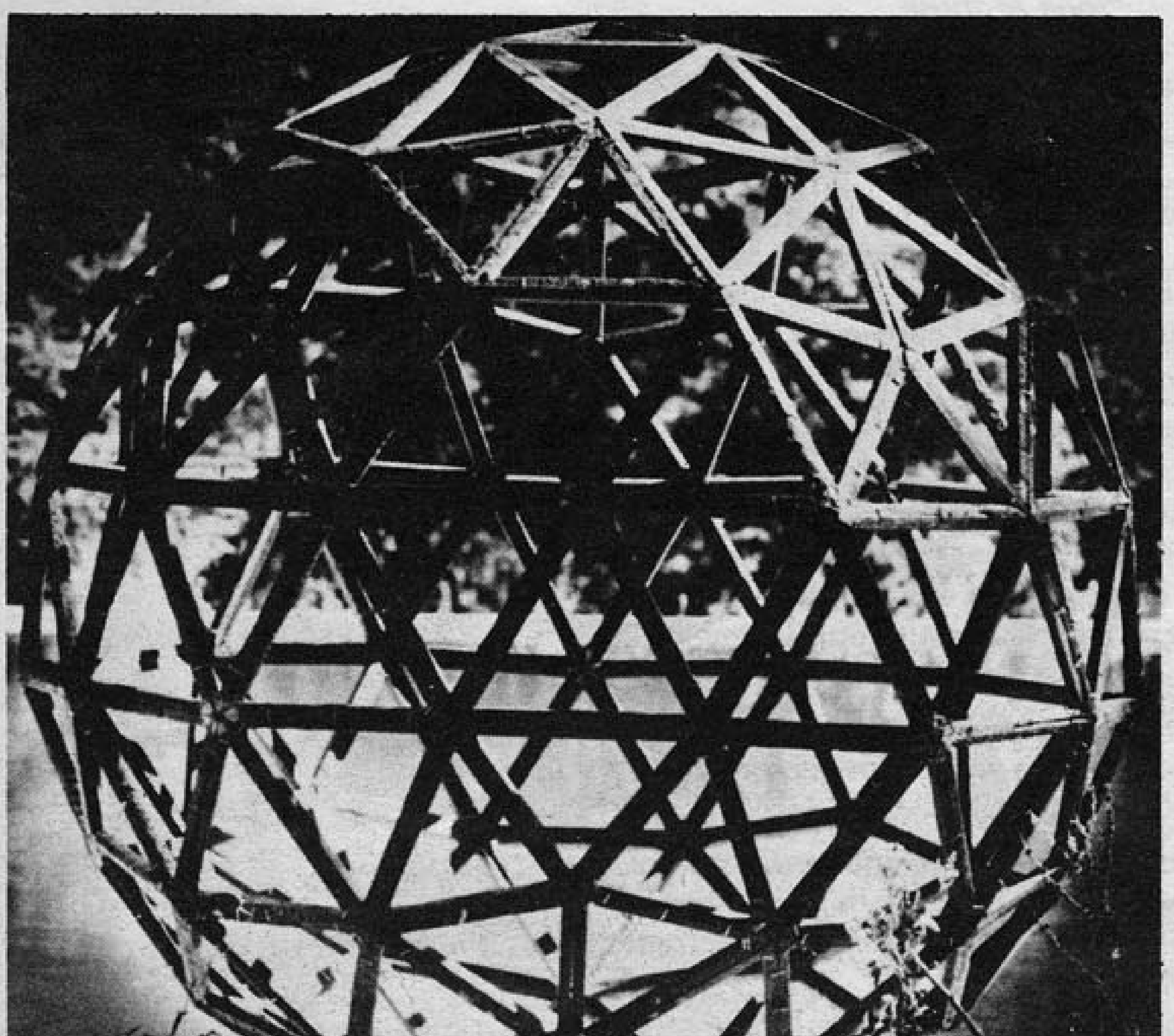
R. Buckminster Fuller's sun dome plans were originally published in the May 1966 issue of *Popular Science.* The plans were then improved and blueprinted and are available for $5 from

*Popular Science Monthly*
355 Lexington Avenue
New York, N.Y. 10017

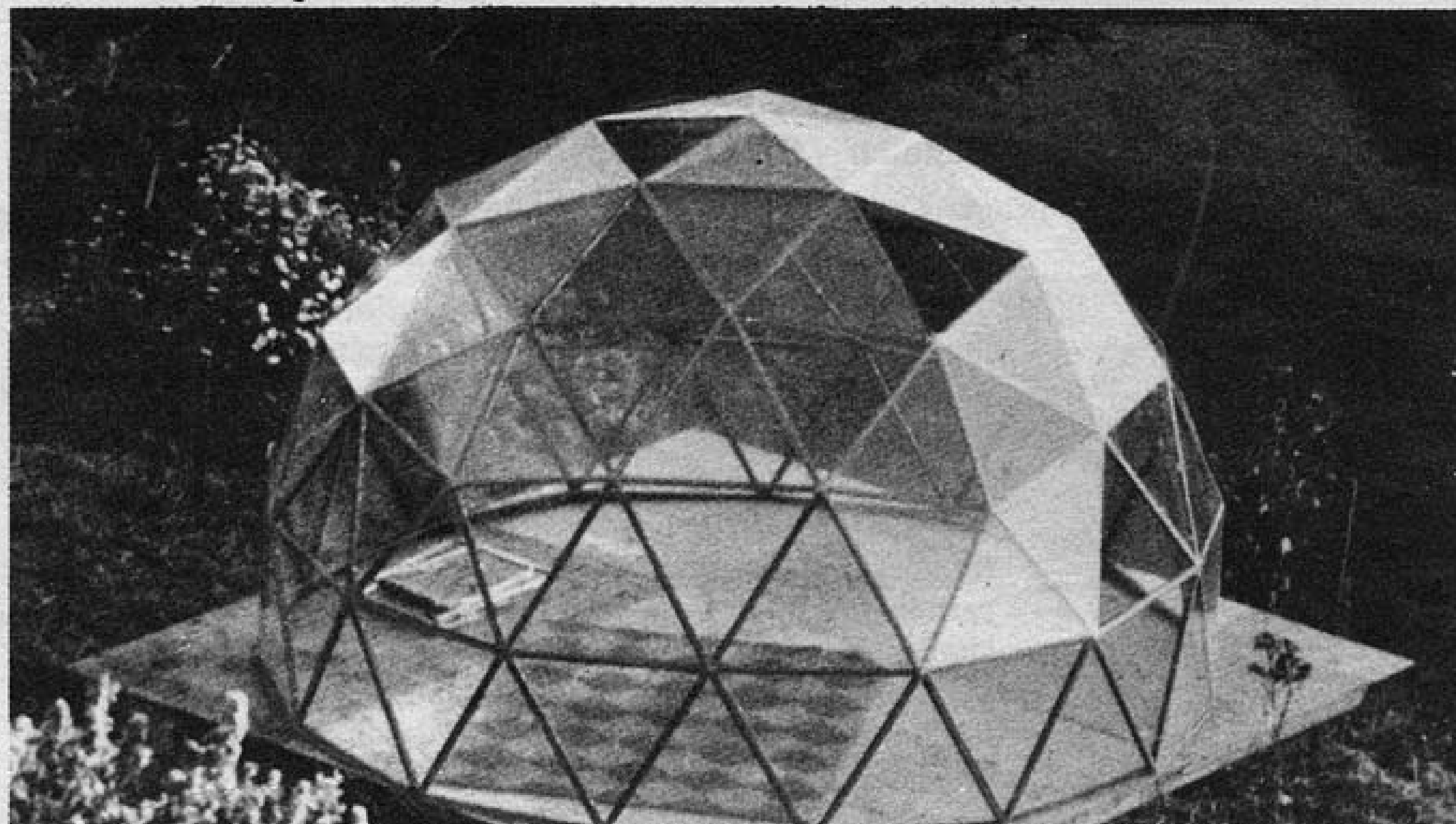
For the fee you **receive clear and simple instructions** for making a 3-frequency 3/8 sphere, polyethylene skin greenhouse or swimming pool cover. A simple system: two triangles make the entire dome and a hand stapler is the only fastening device used.



**Then I made this 8' dome, again of redwood scraps put together with staples. It didn't take too long, and I learned a great deal by being able to crawl inside it. I covered different triangles with cardboard, testing different window patterns. Note the gap between triangles from not mitering struts.**



When I first got the plans, I made a model of D-Stix. Next, this 1-meter-diameter sphere from redwood scraps ripped on a table saw. I first put it together with staples, then removed staples and glued it together with hot melt glue.



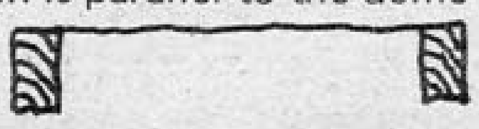
The next thing I tried was this 4 meter vinyl-skinned dome. It differs from the sun dome plans in that it had an extra course of triangles at the bottom, making it a 5/8 sphere rather than 3/8; it is bolted rather than stapled together; and the struts are ripped to avoid the gap. We used it for a greenhouse, for guests, and for watching stars on clear nights. It was built in 1967 on a hillside in Big Sur. When you climbed to the top of the ridge, about ½ mile, it looked like a soap bubble glistening in the sunlight.

Order the plans and then consider the following modifications which we have worked out over the past year. A good reason to get the plans is for the clear diagram of putting together a 3-frequency dome. Also, if you do not want to get involved figuring chord factors, sizes are given for making 16 1/2', 25' and 30' domes.

**Making 3/8 sphere or 5/8 sphere**

Make the model described on page 6 and decide if you want to make a 5/8 sphere rather than the 3/8 sphere specified in Sun Dome plans. If you make a 5/8 sphere, the dome will be much more spacious, you will use 40% more materials, and you must make 30 additional large triangles which will make up the bottom course. Neither a 3/8 nor a 5/8 sphere will sit flat(see page 22). With a 3/8 sphere your dome diameter has to be about 30' before you get some standing room at the sides.

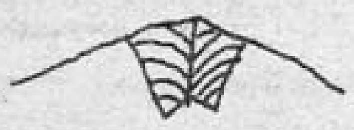
**Strut size:** The 1/2" x 3/4" strips (actual measure) as recommended may be too light, especially with the 30' dome. Jay recommends 3/4" x 1" true measure. (A "two by four" actually measures 1 1/2" x 3 1/2" Use knot-free wood. Douglas fir has high tensile strength. The deeper dimension is perpendicular to the interior-exterior of the dome, and the smallest dimension is parallel to the dome membrane.



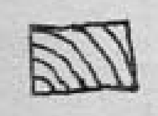
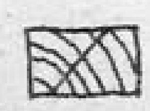
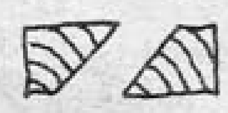
**Strut shape:** If you build the dome according to plans, with regular rectangular wood strips: 

you will have a gap when you put it together: 

(See next page: "Ripping")

If you want struts to fit together tightly, 

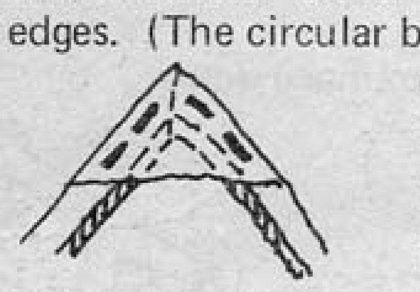
rip to a 7° bevel on a table saw. Purchase wood twice the depth of the strut size desired. If you want struts 3/4" x 1", get

 and rip  getting 

*Important:* When you later cut the end angles on these, remember that with A's and C's there will be a right and left side to each triangle. Look at the plans and drawings of right and left triangles to see this clearly. With B's, where both tip angles are the same, it doesn't matter.

**Tip angles:** These should be cut with a jig (see p. 21). Jigs should be marked so that you can see if they move while you are using them. Cut struts to length first, then cut tip angles. *Remember that if you bevel, there are rights and lefts for A's and C's.*

**Reinforcements:** For greater strength—and especially if the dome will be put up and down often—add triangular braces in the corners: either light metal or 1/8" tempered Masonite glued and stapled to triangle edges. (The circular braces shown in the Sun Dome plans don't work too well.)

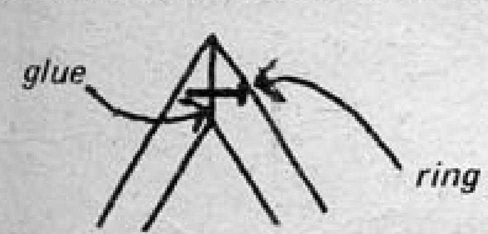


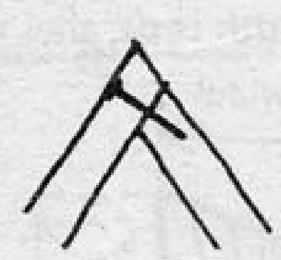
These will also prevent the dome from falling apart due to wind fatiguing the staples at vertices.

## new ideas

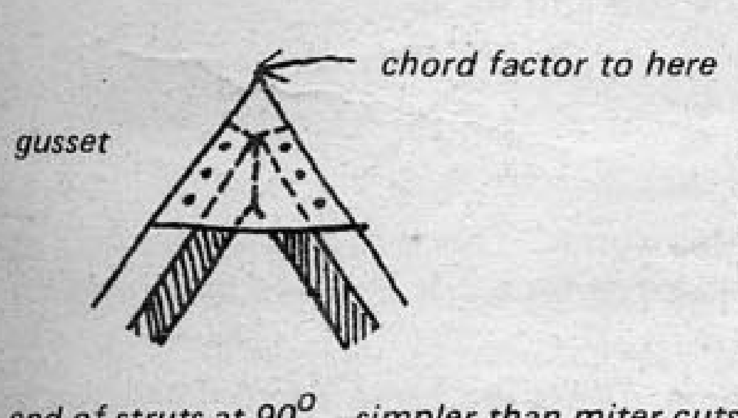
Here are some alternative (and untested) ways of fastening panel frames. We haven't tried any of these, so if you decide to try one of the methods, be sure to make some test panels-a pentagon or hexagon will tell you how things will fit together.

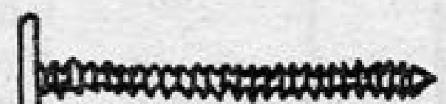
–use best quality epoxy or construction adhesive with countersunk wood screws, ring shank nails, or threaded nails.

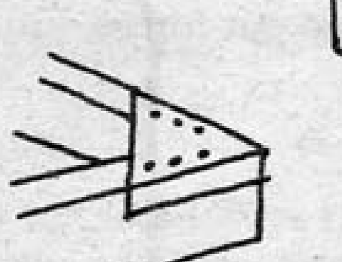



–use a plywood or metal gusset at vertexes, glue-nailed or screwed on. You might be able to avoid cutting strut ends this way.

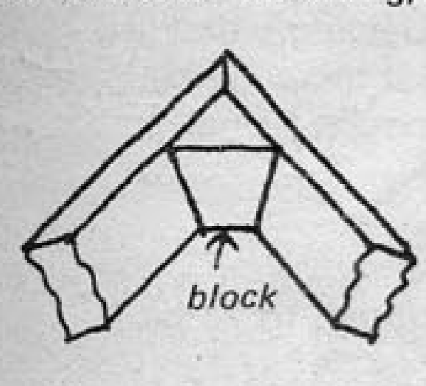


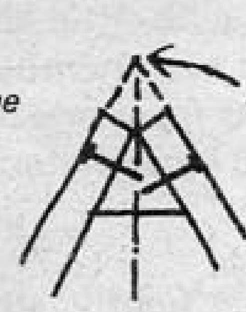



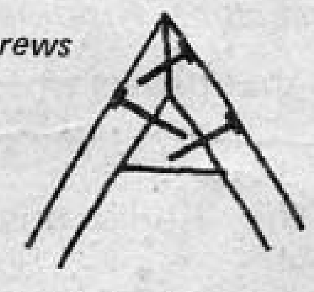



*Gussets on inside (of dome) can be nailed on top of wood frame. However, on outside-facing side of frame, there must be a notch so gusset is flush for putting skin on.*

–fit a block inside the vertex, with glue and screws or nails. With the block you don't have to bother notching, as with the gusset above.



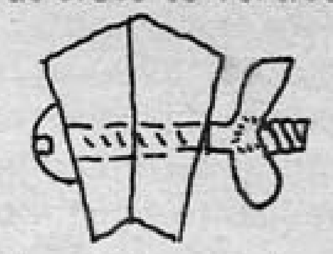




–one of the biggest hassles in building a dome like this is the *ripping* of all strut material. It is possible to make the dihedral angle by adjusting the angle at the vertex and avoid ripping. However, this may only work with flexible skin material, as there would be a gap where rigid skin is applied. Make a test panel to see what happens with the skin.

**Fasteners:**

a) *For easy portability:* bolt dome together with wingnuts, rather than staples: three bolts per strut with washers at both ends. Try to get the end bolts as close to vertices as possible. If you use bolts, bevelled strut edges are essential.



b) *Pneumatic staples:* Jay made a dome this way, renting a Bostitch staple gun that shot 3/4" x 1" rustproof staples. A backup man outside the dome holding a long stick with padded brick tied to the end is necessary for opposing the kick. Panels are held together with welders' clamps, especially useful if skin has tightened, bowing in the struts. This makes a Sun Dome much more wind-resistant, as the strong lifting forces generated by high winds tend to pull out staples. Small rustproof staples are still used for putting skin on frames; the big gun is used only for assembly. Be careful—the gun is lethal. Bevelled struts are not essential with this method. It is almost impossible to remove these staples, so the dome becomes more or less permanent until demolished.

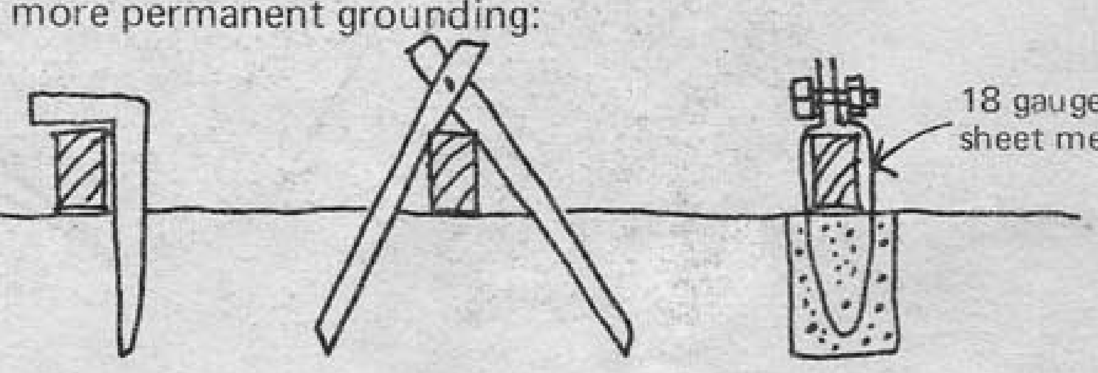
**Staples:** Use only rustproof staples. If you use a Duofast gun, get their Monel staples.

**Floor:** If you do not have a water-impervious floor, the interior of the dome will have a heavy layer of condensation. Since the dome diameters given in Sun Dome plans are not precise, don't make a floor until after the dome is assembled.

**Color code** sticks as you make them, same colors as the model. A's red/B's blue/ C's yellow. Color at tips with a board across struts to get a straight line. Spray paint works well.

Make *extra parts* in case of breakage, also because you may have to custom-make the last triangle if there has been accumulated error.

**Staking:** *Stake down dome securely as soon as first course is completed.* The most common catastrophe with sun domes is to see them sailing across a field. You can bend over a piece of reinforcing steel into a J-shape or drive two pieces of pipe in at cross angles. Or for more permanent grounding:




Do the staking on the inside to prevent wind from kicking in lower end.

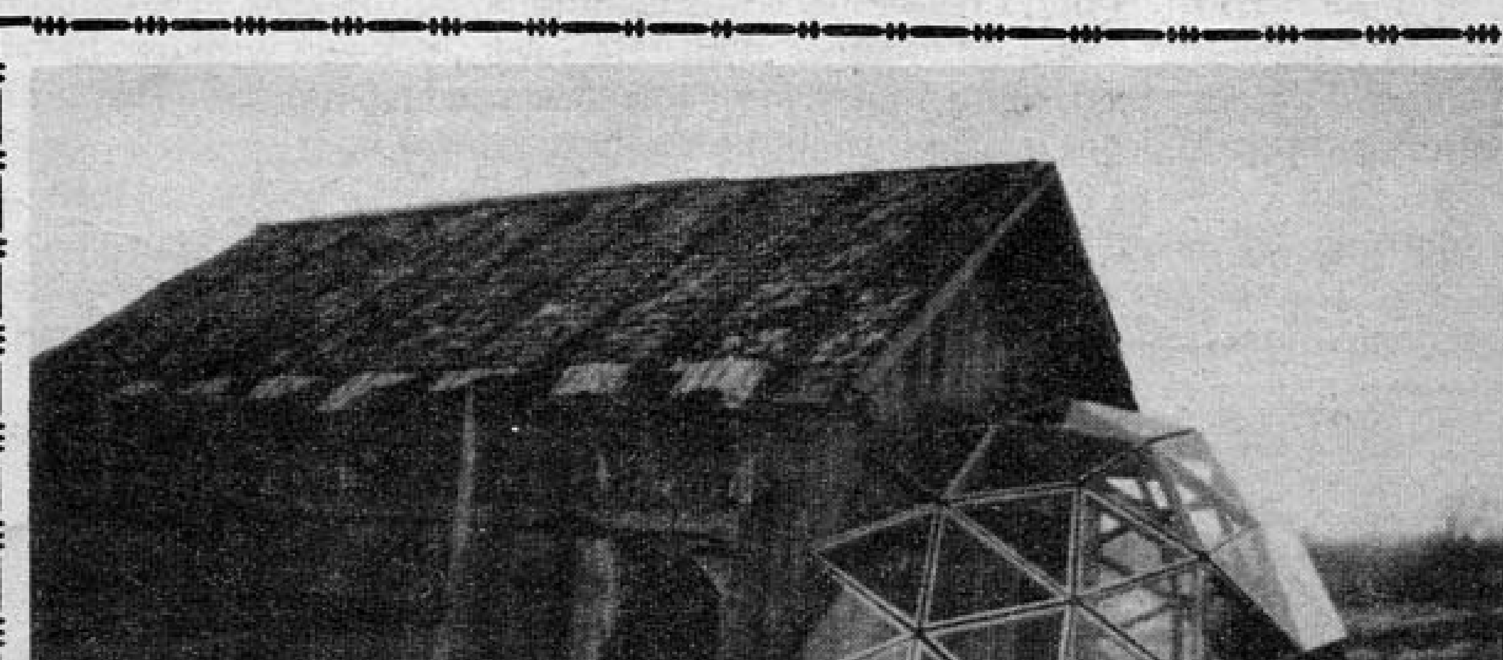
**Putting it up:** Better than the central pole shown in plans is to have a few friends hold long sticks with forked ends to support the panels as they are being fastened together. After you finish the second course, the dome will start supporting itself. The dome must be on flat ground or it will be difficult to assemble.

**Stapling skin to frames:** Staple every 3". Wrap skin around three sides of strut, then staple. If you staple skin on in warm weather it will contract (tighten) in the cold. If it is very warm, don't stretch the skin too tightly as it may pull things apart when it is cold.

**Waterproofing seams:** Vulkem sealant might work (see page 78) or tape with "silo tape", available in farm stores, or vinyl electrical tape. Black lasts longest. Tape should be at least 2" wide. Tape will greatly increase the dome's ability to resist wind lift forces pulling out staples.

**Vents:** Make some at top, into and away from prevailing winds; and some at floor level. You can do this by unstapling a panel, hinging one edge, and taping over the edge for waterproofing. Waterproof two other edges by stapling thin aluminum flashing strip that overlaps neighboring panels several inches, bent to fit. Do not make vents or doors in a way that leaves two adjacent triangles open, or you will weaken dome.

Drew Langsner and Jay Beckwith made a 30 ft 3/8 sun dome with polyethelene skin and wing nut fasteners. They ran an arc of aluminized mylar windows over the top. They put it up in a grove of trees at Peradam, a meeting of educators and builders on a ranch in Santa Barbara in 1969. At the Big Sur Folk Festival in 1970, Wayne Cartwright built a 4-frequency sun dome covered with blue and green vinyl. Putting up a dome with everybody working together is a good way to start a festival, or an outdoor meeting.



**Cornville, Maine**

*Tom Hilmer built a 4-frequency 1/6 sphere sun dome greenhouse, mounted it on a stone wall, and attached it to a house built in 1770 in Cornville, Maine.*

*We don't have construction details, but it looks as if it's made of 1 X 2's, not beveled, put together with two bolts per strut.*

# BIG SUR DOME

I first heard Buckminster Fuller when I was helping to build a huge house in Big Sur. The house was over 3200 sq ft of floor space and was being built of used bridge timbers from an old redwood bridge that had spanned the Russian River. It was a post and beam type construction, with members 6" X 16" and 8" X 20" thick, some of them over 30 feet long, which we had to hoist into place with a tractor and a boom.

On a stormy weekend at Big Sur Hot Springs Fuller talked about spinning a dome framework of light members. When I went back to work on Monday, I looked at the ponderous beams we were struggling with, thinking of them in terms of cutting them up into dome struts—soon I quit the job. Appropriately enough, when I went to build a dome shop, our landlords and friends, Boris and Filippa Veren gave us some 12" X 12" bridge timbers from the old Burns Creek Bridge. After getting all the nails and bolts out, these were ripped into strut material by the Carmel Valley Lumber Company and I was on my way to building a dome that coincided with the vision of refining huge beams into thin struts. By comparison with the big house, it felt like the spinning of a spider web.

The skin of this dome was 3/8" rough sawn(exterior grade) douglas fir plywood with water stains that I bought for $2.00 per sheet at a lumber yard in Monterey. Thus, both struts and skin of this dome were of used or reject material.
Pentagons were of clear vinyl, making five large pentagonal windows around the sides, and one clear pentagon at top center for stargazing.

It is a panel frame dome; two different size triangles and four different struts make the entire structure. Using bigger struts and thicker plywood, you could probably build up to a 40' dome using this 3-frequency geodesic pattern.

The greatest advantage of a bolt-together dome such as this, as compared to the hub system wooden dome, is portability. When we left Big Sur, I sold the dome—it was disassembled and moved. The dome weighs less than 3,000 lbs and can be transported in a flat bed truck.

By designing and fabricating a portable structure you will realize a great degree of freedom not possible for the permanent, stay-in-one place house builder. It may mean that you do not have to buy land. With the prospect of packing up your house and leaving, you might be able to lease land in exchange for caretaking. We generally think in terms of a shelter being permanent and immovable, because houses are too heavy, and made of many thousands of different components. However if you do build a dome, and it sits lightly on the land, and if it can travel, you can leave the land as you found it.

Because I knew nothing about caulks, and partially due to the rough texture of the wood, I never succeeded in sealing this dome. Rough sawn plywood is more difficult to seal than a skin with a smooth surface, although with knowledge now available on sealing, I believe even a rough sawn surface plywood dome can be sealed.

This dome was a masterpiece of inaccuracies and poor planning. The strut lengths were + and – ½" in length. Yet somehow it went together. We had to keep trying different panels to find the right fit. I don't recommend this technique, by the way, as it could have ended up with a dome that didn't go together at all. However, luck was with us. In fact, the rains held off until we were tightening the last top clear triangle in place. Tightening up the last bolts, the rain drops begain hitting the top clear pentagon.

The next morning I came out and tightened all the bolts in the dome. The dome cracked and creaked into tighter tension as the triangles were pulled close together. We played some Bach organ music inside. At the heart of each hexagon were small amber stained glass windows.

### VITAL STATISTICS

Geometry: 3-frequency geodesic, 5/8 sphere, icosa-alternate breakdown, vertex zenith

Diameter: 8 meters(about 26' 3")

Floor area: 530 square feet. (Even though struts are measured metrically, other dimensions are still in feet as comparisons with other structures are inevitable.)

Surface area: 1371 sq ft

Volume: about 5100 cu ft

Lineal feet struts: 1638'

Weight: large triangles: 28 lbs each
small triangles: 10 lbs each
total: 2400 lbs

Date built: spring, 1968, Big Sur, California

### DOME INGREDIENTS
**Frame & Skin**

–30 pieces 3/8" plywood–4' X 8' sheets
–about 1700 lineal feet strut material(*after* ripping to bevel)
–3 rolls 48" X 50' vinyl. The 48" just makes it as covering for small triangles.
–30 lbs hot dipped galvanized 4d or 6d nails
–20 tubes waterproof construction adhesive
–1 box 5000 Monel(rustproof) ¼" Duo Fast staples
–enough caulk and/or tape for about 800 lineal feet joints
–500 ¼" diameter galvanized bolts. Length of bolt depends upon total width of bolted–together struts. I used 3½" bolts for 3" struts

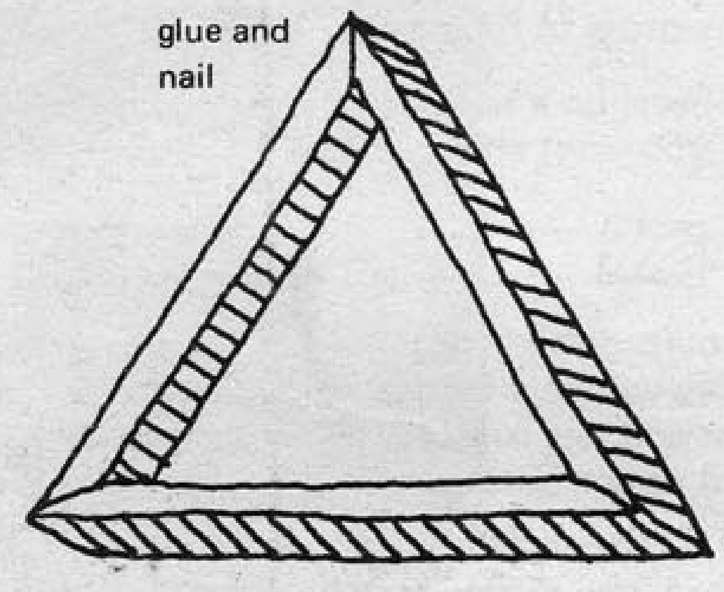
**Concrete floor**

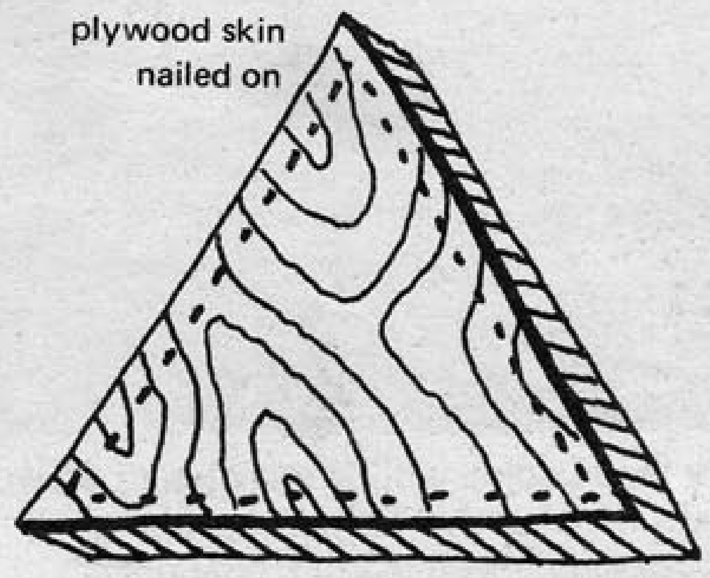
–5 yards sand & gravel
–20 sacks cement
–30 8 1/2" anchor bolts
–500' 6" x 6" steel mesh
–500 sq ft polyethylene
–about 90 lineal feet 1/2" reinforcing steel

### BUILDER'S INSTRUCTIONS

In describing how it was built I'll use the same strut designation as do the Sun Dome plans (A, B1, B2, C) to avoid confusion. If you are going to build this type of dome, you should buy the Sun Dome plans (see p. 14) as the blueprint may answer some points not covered here. Be sure you make a model first.

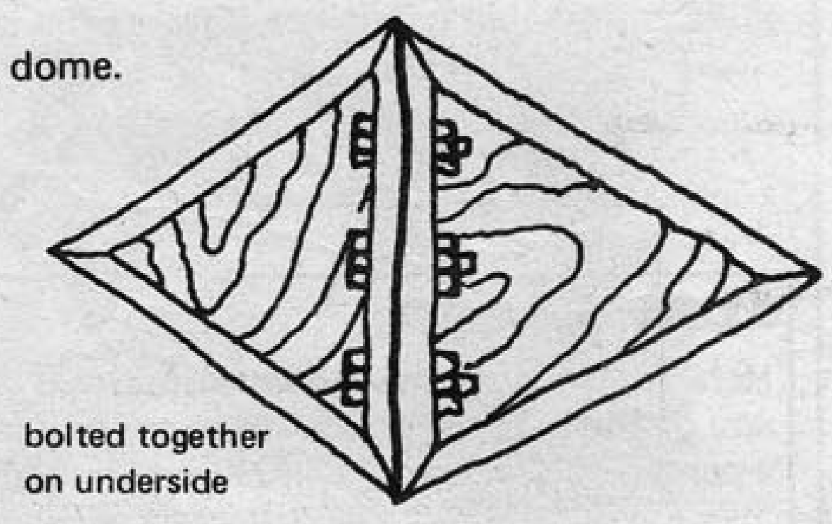
First, struts are cut, then put together



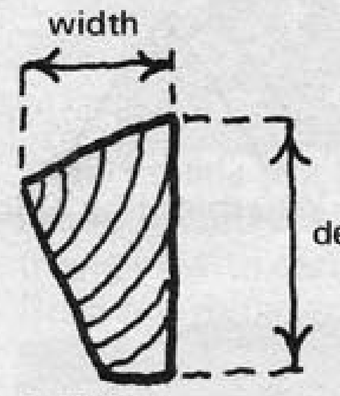

Then plywood is cut, and attached to triangle

Then panel frames are bolted together to make dome.




**Cutting Struts**

Size: Struts have depth and width. Depth is perpendicular to interior-exterior of dome; width is parallel to dome membrane.




With wooden domes, depth should be greater than width, as plywood is girdled around the dome, providing lateral support, while the depth of the strut provides the strength for in and out forces.

I used 3" X 3" s, ripped in half at 7° bevel, for this dome. This was heavier than necessary. A 2 X 4 ripped in half would be adequate, even a 2 X 3 would be strong enough.

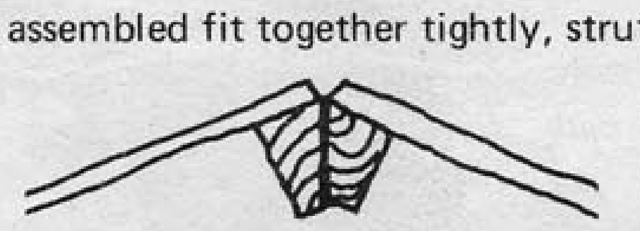
We'll describe the ripping process used in this dome. There are some alternative ways to prefabricate the triangle frames described on p. 23. So that panels when assembled fit together tightly, struts are ripped to 7° bevel.

Buy your lumber so that it can be cut up with little wastage. Calculate the correct lengths to order (lumber comes in even numbered 2-foot increments), decide whether to get two or three lengths from one piece. Douglas fir has very high tensile strength and makes good strut material.

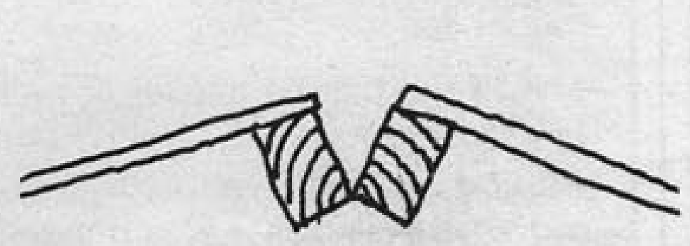
*First step: Ripping*

So that panels when assembled fit together tightly, struts are ripped to 7° bevel

so they fit like this



If you don't bevel they'll be like this



I discovered this when I put together a little 8' dome with staples—I hadn't thought of it before. An example of why model making is invaluable, and can prevent full scale errors.

You'll need a table saw. Set it at 7° and rip all strut material. Sharpen the blade frequently. Don't overwork the saw's motor. This is a lot of ripping. Wear goggles and make sure each piece is tightly against the fence. Have a helper pull the wood through. Make sure you rip exactly in the middle.

### Table of Struts

Cut struts in this order, after they are bevelled; for working in meters, get a metric tape measure from a drafting store.

| Strut | Number to Cut | Length | Rip to Bevel of | Tip Angles |
|---|---|---|---|---|
| A | 30 rights<br>30 lefts | 139.4 cm<br>(54 15/16") | 7° | 35° A 27½° |
| B1 | 30 | 161.4 cm<br>(63 9/16") | 7° | 27½° B1 27½° |
| C | 75 rights<br>75 lefts | 165.0 cm<br>(65") | 7° | 29° C 30½° |
| B2 | 75 | 161.4 cm<br>(63 9/16") | 7° | 30½° B2 30½° |

*Second step: Cutting to Length*

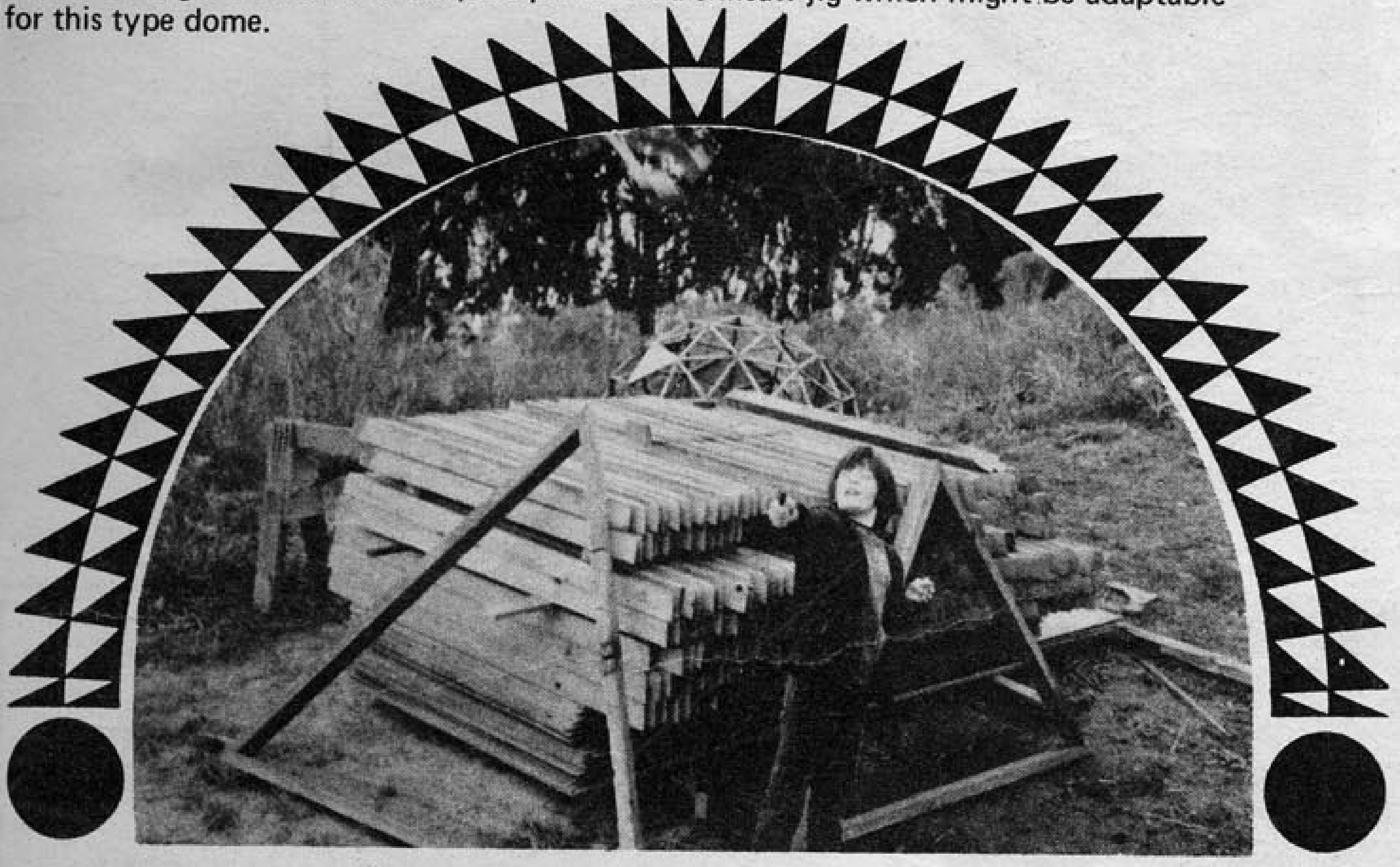
*Important:* Both small and large triangles have a *right* and *left* side (A's and C's) if you bevel struts. Therefore when cutting A's and C's to length, you will cut 50% *wide side up*, 50% *narrow side up*.

Start with sticks stacked in three piles. Cut each strut an inch or two longer than final length so that they are easy to maneuver. Allow yourself more margin if you wish.

Once the angle is set, cut all pieces you have to that angle.

Cut enough extras to make up for mistakes.

A radial arm saw is the best tool for this, as it is designed for cutting many pieces of wood to the same length. This is one of the most important steps in building this dome, as a slight error in strut length will throw the entire triangle off. Have someone else check each piece against a master piece as you cut, so stop does not creep.
If you can't get a radial arm saw, see p. 127 on a skilsaw jig which might be adaptable for this type dome.



*All the struts and plywood for the Big Sur Dome.*

**Shop Yoga**

If your radial arm saw guage is such that a cut at 90° to the piece of wood you're cutting reads 0° on the guage, the angle you set should be the complement of the tip angle. Since our saw's guage was like this, here is how we cut struts.

**A – 62 1/2° – first cut**

Set saw for 62 1/2°. Cut 50% of A's broad side up, 50% narrow side up, trimming a little off the end. Stack in two piles.

**B1 – 62 1/2° – first & second cuts**

Cut one end of all B's.
Set stop for B's at 161.4 cm (63 9/16"), turn over and cut other end to length.

Color code B's—one blue stripe in middle—narrow side.
Stack in two piles.

**A – 55° – second cut**

Set saw for 55°. Set up stop for A's at 139.4 cm (54 15/16"). Cut 50% wide up, 50% narrow up.

Color code 55° tips of A's red.
Stack in two piles.

**C – 61° – first cut**

Set saw at 61°. Cut 50% wide up, 50% narrow up. Stack in two piles.

**C – 59 1/2° – second cut**

Set saw for 59 1/2°. Set stop for C's at 165.0 cm (65")
Cut to length. 50% wide up, 50% narrow up.
Color code 61° ends of C's yellow.
Stack in two piles.

**B2 – 59 1/2° – first and second cuts**

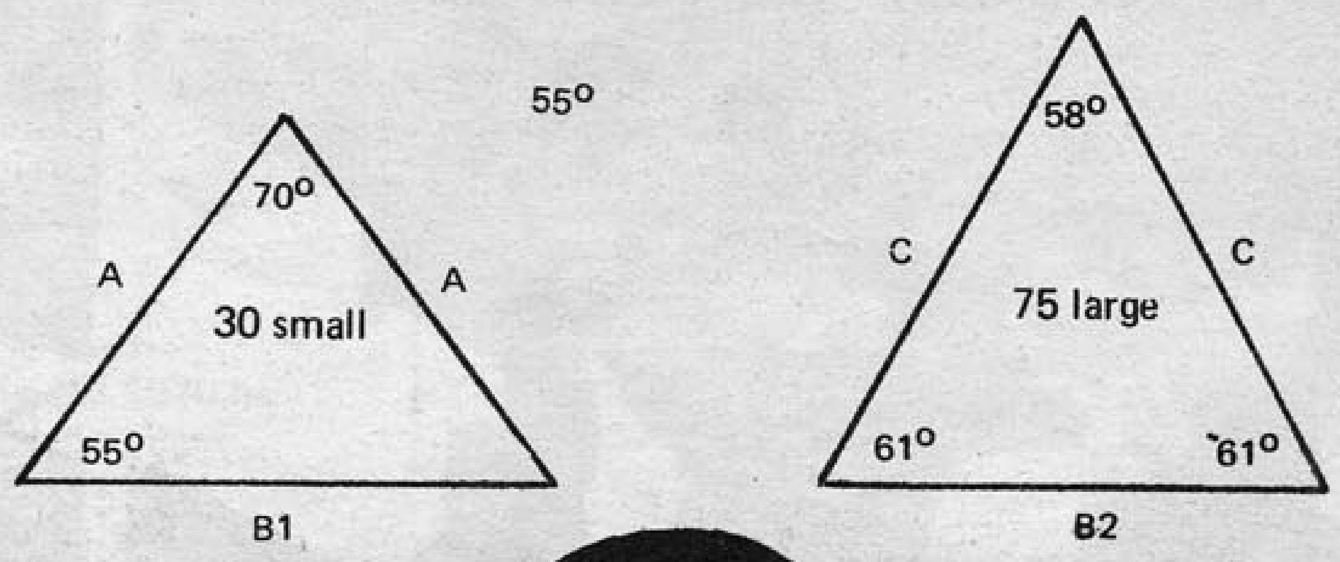
Cut 59 1/2° end of B2's.
Set stop for 161.4 cm (63 9/16").
Cut other end. Be sure to flip for second cut.
Color code B2's—two blue stripes middle.
Stack in two piles.

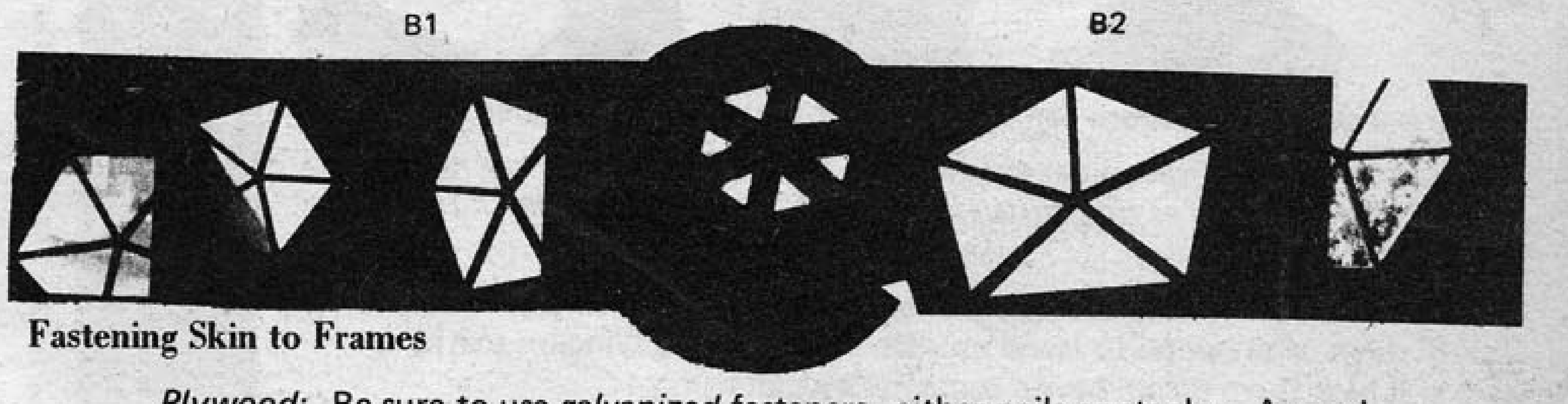
**Drilling Struts for Bolts:** You can drill struts now by making a jig. Or you can drill as you put up the dome. If you jig drill, make holes 1/16" oversize to allow for errors.

**Putting Frames Together:** I used glue at the tip ends, and 16d threaded nails, which have five times the holding power of ordinary nails. Hot dipped galvanized nails work well too, as they have a rough barbed-like surface. Screws can also be used. The holding power at vertexes is more important with triangles that are covered with flexible material than with those covered with rigid skin.

**Cutting Plywood:** See p. 22 on jigs. There are 30 small triangles, 75 large triangles in the 5/8 sphere. Plot cutting on graph paper to maximize use of plywood. If you use entire triangles for windows, subtract from number of pieces of plywood you cut.

I cut my base triangles (15 of the large size) 5" larger so that they extended down past the floor for water run-off. This can also be accomplished with flashing or pieces of plywood.

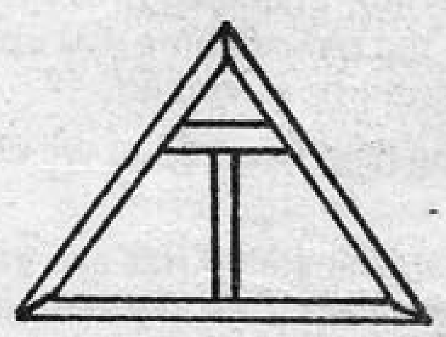


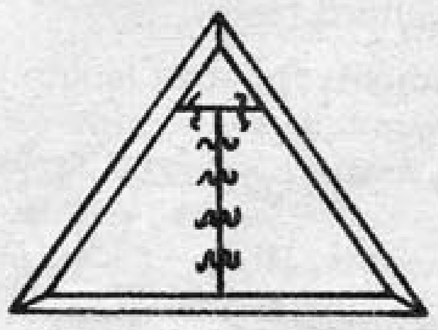
**Fastening Skin to Frames**

*Plywood:* Be sure to use *galvanized* fasteners—either nails or staples. A good staple gun—if staples have holding power—will save time. I used 6d hot dip galvanized nails, one every 6" or so and a bead of waterproof construction glue between strut and plywood.

Where you have half pieces you should either run a strip of wood down the inside so that both halves can be nailed to it and seal outside seam



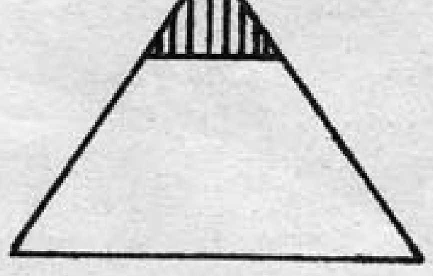
or you should fiberglass the inside of the seam, and waterproof the outside in the same way as you waterproof other joints. The halves are put together with 3/8" corrugated fasteners:



Nailing is done on a hard surface like concrete. If you fiberglass the inside (a 4" wide piece of fiberglass matt—cheaper than cloth—will do), do it *before* fastening plywood to frame.

This is an important step in plywood dome making. You must utilize halves, and the halves are usually the trouble spots.

With the large triangles of an 8 meter dome there is a 4" opening here:



This can either be patched with plywood or colored glass. I used amber glass; it made a beautiful hexagonal pattern around the hex hubs.

Leave the plywood off at least one large triangle, for entrance into dome. Seal edges by painting so if water leaks it won't delaminate plywood.

If dome is to be painted it will be easiest to spray paint in shop before assembly.

**Fastening Window Material to Frames**

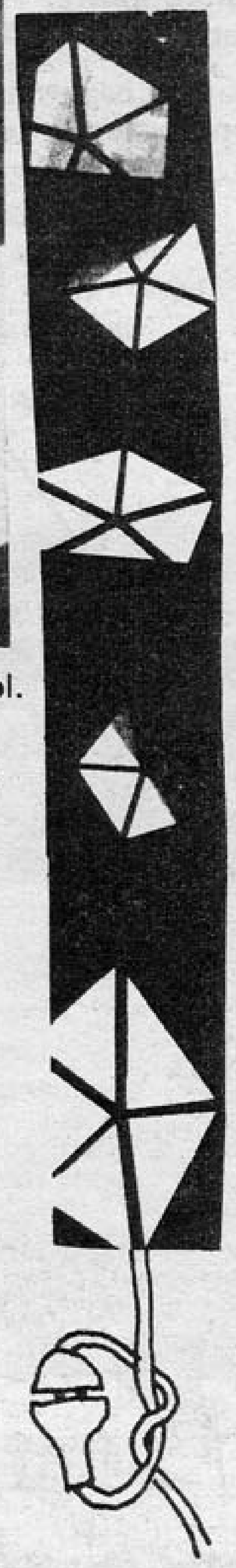
Whatever you use for windows—vinyl, mylar, fiberglass, glass, etc.—be sure to put a strip underneath it on strut so that when dome is assembled the window will be flush with the plywood.

If there's a gap you'll have waterproofing problems.

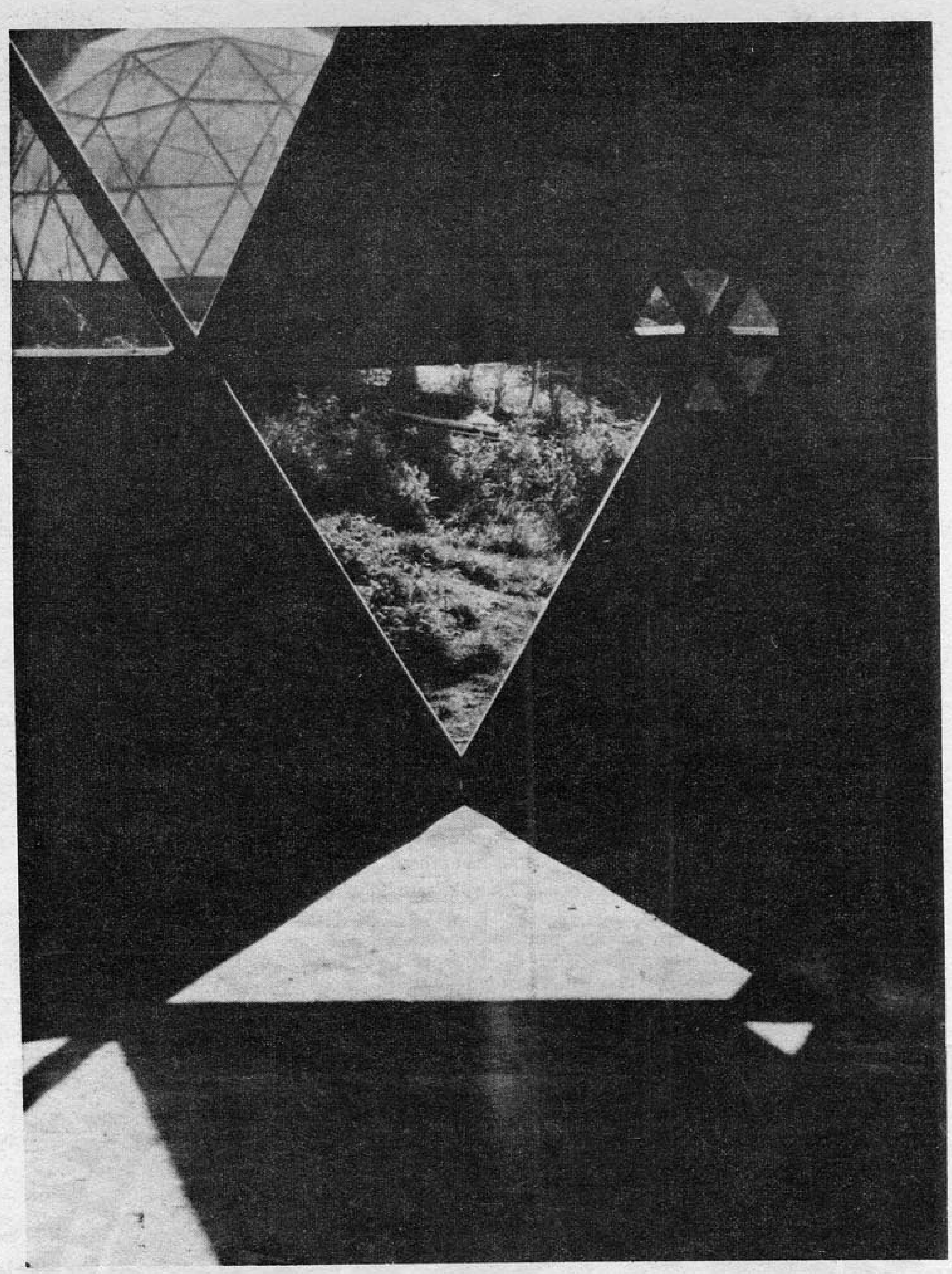
Plexiglass, lexan or glass have a much longer life. However, if you can only afford vinyl (or polyethylene), here is how to adhere it to frames:

Clear your working table of everything but the roll of vinyl. Roll vinyl out. Put triangle on, face down. Staple one edge, every 4" or so. Cut vinyl. Then staple second or third edges. Make fairly taut, but not too tight. When dome is put up, it will stretch tighter when struts are pulled together. In warm weather, vinyl will loosen; in cold weather it will tighten. Thus put it on the frames at a medium temperature. If you put it on in hot weather, and stretch too tightly it might rip apart when it gets cold.

## PUTTING IT UP



*Tie a knot like this connecting drill cord to extension cord so it won't slip out when you pull on it.*



**Three is a good crew. More can be helpful, if you have good order and control.**

One person should direct what goes where. For this purpose, *your model—color coded the same as the struts—is placed in the center for quick reference. See pp. 5-6.*

A scaffold with wheels and wheel-brakes is highly advisable here, with a 4' x 8' sheet of plywood to stand on. Don't leave tools lying on scaffold, as you'll kick them off and onto someone's head.

Start with bottom course. If you are drilling bolt holes as you go, drill one in the middle, one as close as you can get to each vertex. Clamp struts together as you go if it helps. Drill holes the same diameter as bolt as it makes a tight fit. Use washers, both sides. Pound bolts in with hammer.

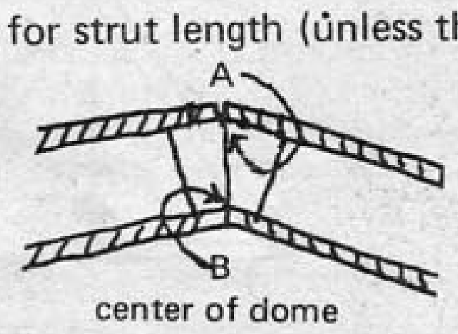
Two of you can tighten as you go, using ratchet wrenches. A pneumatic wrench would be ideal, like ones used for changing tires. We tightened bolts fairly tightly, but waited until the entire dome was up before the final tightening. This gives more flexibility as you go.

We had no need of braces. The dome held itself up as we went. With each course, the dome gets stronger.

You may have to custom fit the final triangle. After everything is in place, work from top down and give bolts a final tightening. This is a very exciting phase. You'll feel the dome creaking into tighter tension, becoming stronger, the membrane uniting.

Calculating for interior membrane: if dome diameter is 40', it is 20' from center of dome to A. To calculate for interior membrane, subtract distance between A&B from radius, and multiply times chord factor. If AB is 3", you multiply 19' 9" times chord factor.

Note that you use the same measurements for strut length (unless there is a connector) and membrane length.




Put a mast on the top for climbing.

(See Table of Contents for **Doors; Windows; Vents; Sealing joints**—don't use fiberglass tape on this dome; it moves around a lot, and **will crack tape.**)

## Plywood Domes

In Domebook One I wrote a section called About Plywood Domes wherein I said we had to be careful about using wood, since the forests are disappearing so rapidly, and that plastics, metals, and ferrocement seemed a better dome skin in that they hold up better to the weather.

The advantage of plywood is that it's strong, relatively cheap, can be cut out and assembled with hand tools, and it feels better to a lot of people than metal or shiny plastic. Yet I had a great fear, especially after driving to Canada on Highway One, that forests were disappearing fast. The loggers have left a camouflage strip on the highway, behind which everything is ruthlessly destroyed. Lionel, a fisherman, tells me that viewed from the sea, the Oregon forests are barren.

Redwoods, stately and refined, are practically gone. Back in the hills in Big Sur are clusters of redwood trees—they seem to grow in families. Underneath their branches is a distinct peacefulness, calm, a lot of moisture, and there must be high negative ionization. The high quality redwood in lumber yards is from 200-800 year old trees; the lower quality at least 40 years old. Thus, I'm totally opposed to buying new redwood.

Douglas fir, however, grows much faster, and is one of the highest strength(in tension) woods. We used douglas fir for strut material with the Pacific domes. The next year we planted 300 Douglas Fir seedlings. In California seedlings can be obtained from Davis Headquarters Forest Nursery/Rt l, Box l410/Davis, Ca. 95616. 500 trees are about $15. Planting the trees is a wonderful experience. As you plant, you begin to notice where trees grow. On our land, fir seems to grow on ridges, on upper sides of small valleys. The madrones and oaks down in the canyons and creek bed areas.

It's hard to tell what to use for dome materials, as one must consider the practical and aesthetic aspects, and overall abundance of any material. If you are going to use wood, a geodesic dome will use the least amount of it. An ecological solution might be used wood, or wood in lengths too short for other uses as struts, with other materials for the skin.

## writers

### Jig

*When I built my Sun Dome, I decided that, the representations of the blueprints to the contrary, staples were an inadequate method of putting together the triangles both from the point of view of strength and ease of transportation and relocation.*

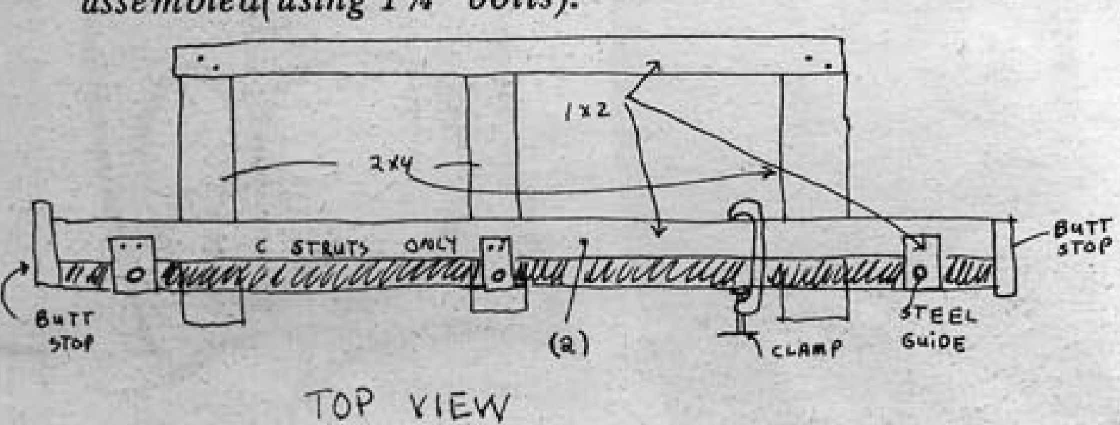
*In Domebook One you suggest as an alternative bevelling the outside edge of the strut and bolting the triangles together, but you had no drilling jigs. Here is the one I designed:*

1) *There are actually three jigs, one for each length strut. It is a pain in the ass to make up three jigs instead of one that works for all length struts, but this simplifies the jig considerably and permits three people to work at the same time. Depicted below is the C-strut jig.*

2) *It is a C-strut jig by virtue of the fact that the fence (a) is the same length as a C-strut.*

3) *Strut is inserted* beveled face down *against the fence so that its wide(exterior) face is against the fence. The guides are ¼" internal diameter pipe sections, easily obtained at your local friendly hardware store. They accomodate a ¼" drill nicely, although at first they are a snug fit and require occasional lubrication with graphite to prevent them from turning with the drill.*

4) *I drilled each strut 2½" from each end and at the centre. I used 1/8" bolts with wing nuts and two washers. If you drill at less than 2½" from the ends, the bolts will not go in after the triangles have been assembled(using 1¾" bolts).*




George M. Klopfer
Baltimore, Maryland

### Space Age

*...please think about where non-lumber building products come from and what their manufacture and use does to the landscape and the ecology, and whether they can be used indefinitely. If "space-age" materials(and the accompanying ecological problems each new process seems to produce) are needed to make domes work, perhaps we should give up the idea of living in domes.*

*Thanks for listening to me. And thanks for an otherwise fantastic book.*

*Sincerely,*
*Susan Gallagher*
*Lucas Book Co., Berekeley, Ca.*

### Moscow, Idaho

The world's oldest living thing is considered to be a bristlecone pine estimated to be 4600 years old.

### Forests

*While we both share the inspiration of R. Buckminster Fuller, your comments on the use of forest products vs. petroleum and mineral products in my opinion lack integrity, not by design but perhaps misinformation. While you do not condone petroleum derivatives, you do promote mineral material, and while acknowledging technologic-economic advantages of wood products, you condemn its use. To this let me offer these comments:*

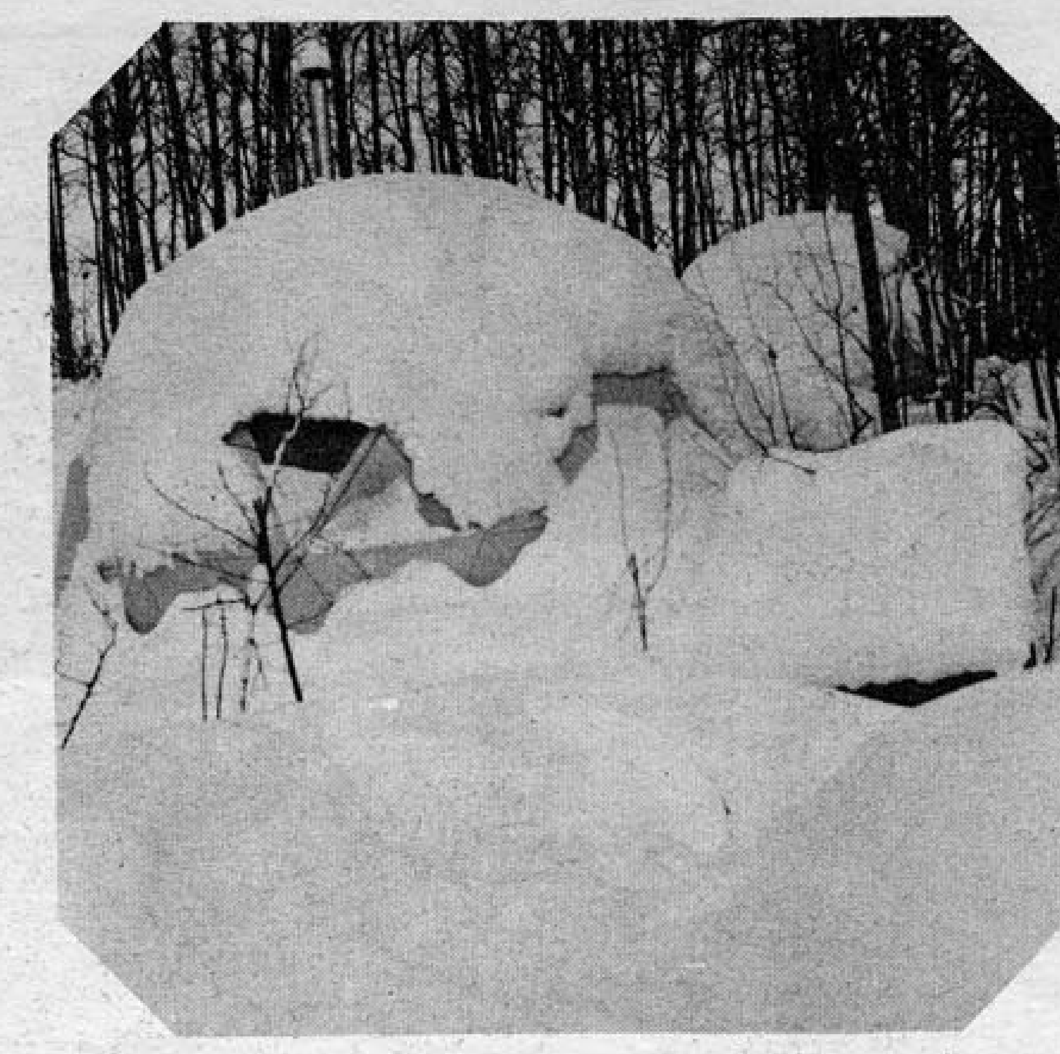
*1. Forest products, wood fibre and cellulose from trees is the* only renewable *resource on your building materials list.*

*2. A single tree, on average forest soils, can produce enough wood fibre to build an eight meter dome in about 40 years. By replacing the used tree with a new seedling, in the subsequent 40 years you will have enough wood for a replacement dome. This could be repeated endlessly, provided man doesn't destroy the earth first. The entropy loss from this cycle is nil, as it would be no different from letting the original tree reach its pathological maturity and subsequently reproduce itself. The original fibre if harvested can also be recycled for use over and over, or if you're still worried about removal of something from the earth, then throw the old wood on the ground and it will rot and return to its original components, just as the over-mature tree would have done anyway if not harvested. If you can explain to me how minerals retched from the earth, or petroleum sucked from the earth could serve more efficiently, then seriously, please let me know. In fact, recently it has been suggested that wood fibre might be the most efficient, least energy using(entropy). material on the earth for* fuel.

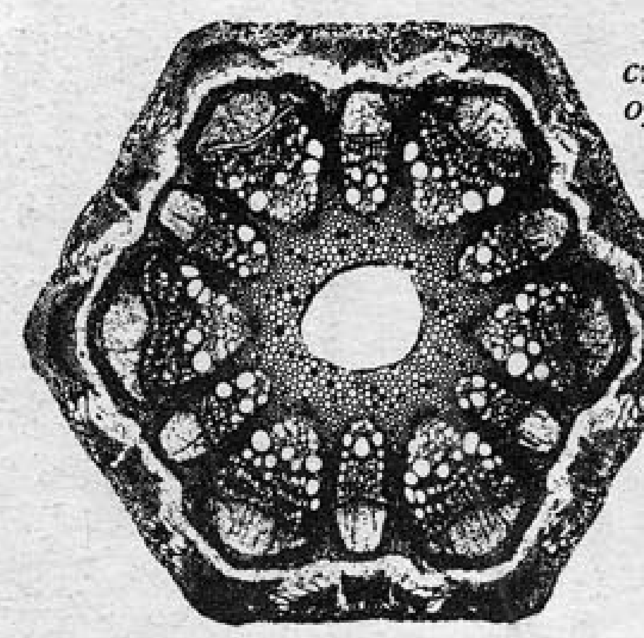
*Please do not think I am trying to condone the current practices of the forest products industry. That subject awaits a better day.*

*Warren S. Halsey*
*Forester*
*Orinda, California*

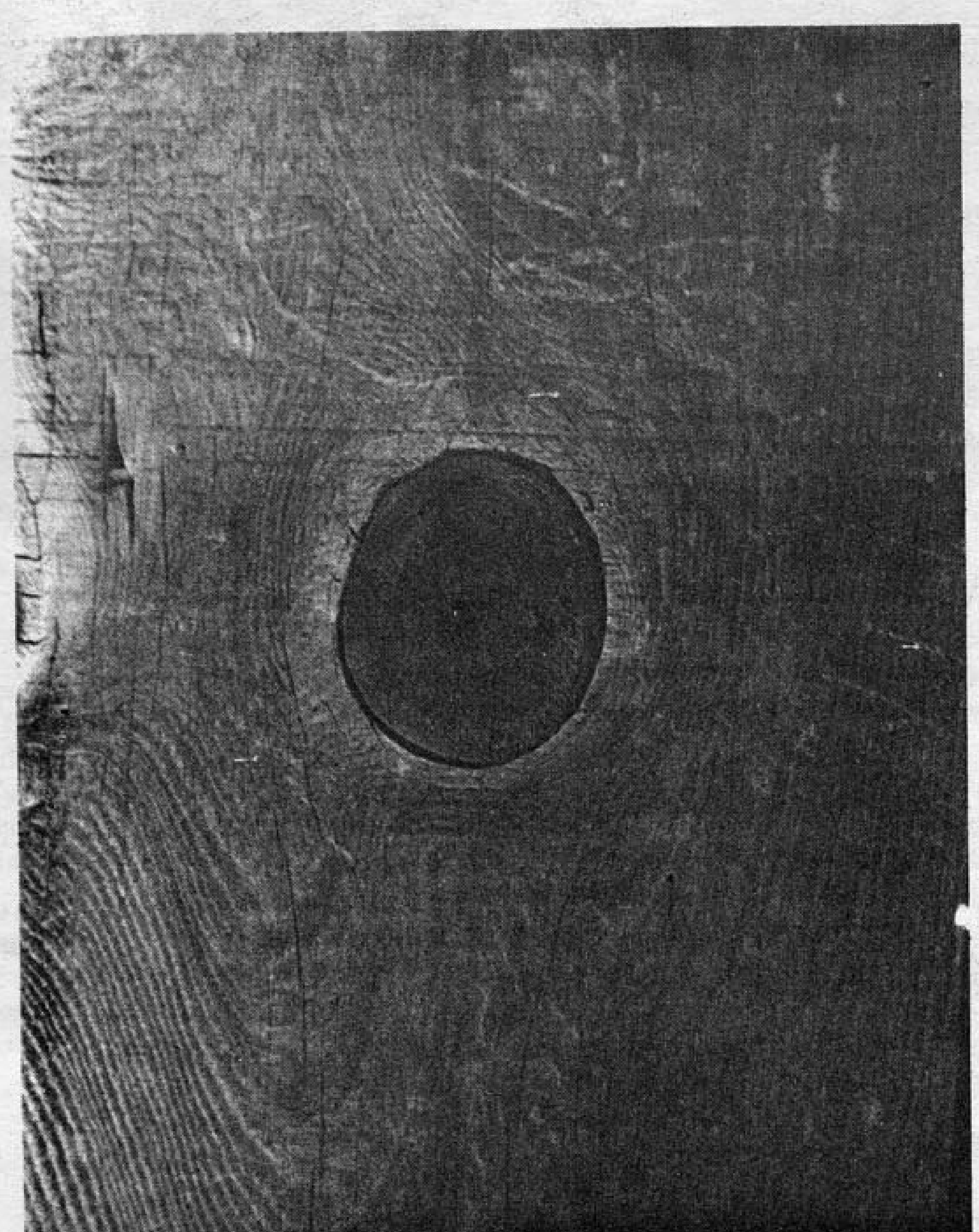
# Woodwork



**Len Waks went to Canada from Stanford to teach** philosophy at the University of Alberta. In fall 1970 he built a dome in the woods near Edmonton from plans for the Big Sur dome in *Domebook One*. He worked out a sealing system which is apparently keeping water out, and the dome seems to be handling the heavy snow loads.



*cross section of twig*

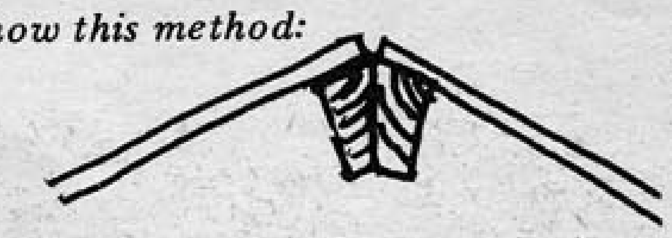


*The absence of all paint, varnish, oil, or filling, which too often defaces our rooms at home, is at once remarked; and the ridiculous absurdity of covering a good grained woodsurface with paint, and then with brush and comb trying to imitate Nature by scratching in a series of lines, the Japanese are never guilty of. On the contrary, the wood is left in just the condition in which it leaves the cabinet-maker's plane, with a simple surface, smooth but not polished,—though polished surfaces occur, however, which will be referred to in the proper place. Oftentimes in some of the parts the original surface of the wood is left, sometimes with the bark retained. Whenever the Japanese workman can leave a bit of Nature in this way he is delighted to do so. He is sure to avail himself of all curious features in wood: it may be the effect of some fungoid growth which marks a bamboo curiously, or the sinuous tracks produced by the larvae of some beetle that oftentimes traces the surface of wood, just below the bark, with curious designs; or a knot or burl. His eye never misses these features in finishing a room.*

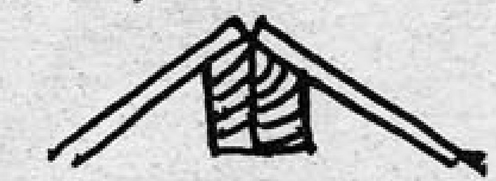
*Edward S. Morse*
Japanese Homes and their Surroundings

### Rapp

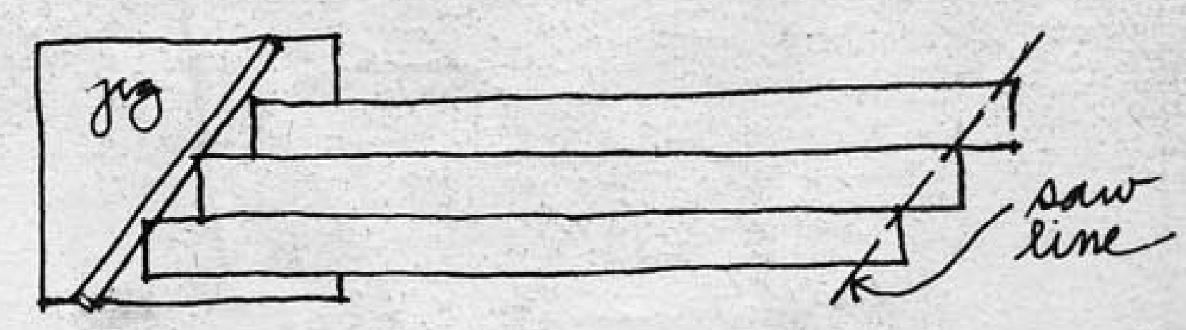
*Regarding illustration of how struts of Big Sur Dome are ripped:*
*You show this method:*



*When bolt is inserted, neither the head of the bolt nor the nut sit flat against the strut. And wood is hard to rip like that.*
*What do you think of this method:*



*Bolt will sit flat. Wood could be easily cut to this shape by making a simple jig:*




*If this idea is no good, please let me know(I'm going to use it if I don't hear from you).*

*Peace,*
*Michael Rapp*
*Florence, Arizona*

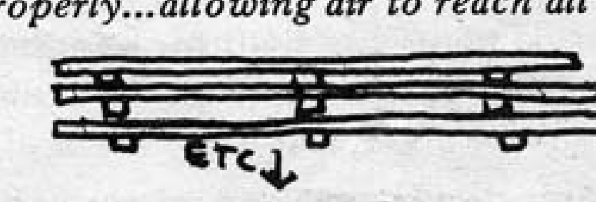
### Porcupines

*Four of us did a dome here in the fall.*
*5/8; 3 freq.; 33 ft diameter.*
*Patterned on the "Big Sur" ideas.*

Suggestions for Builders

1. *Build a model...keep it handy.*
2. Educate! *Save time and hassles by letting everybody in on theory and plans. Do it beforehand.*
3. *Talk to the natives(especially neighbors) when looking at a site...when* they *talk...listen!*
4. *In mountains or snow country(we're both) determine the frost line(depth to which soil freezes) and get your footings well below it.*
5. *Investigate native materials...for practical as well as spiritual reasons...our fieldstone footings were free...lumber is rough-cut pine from the company that sold us the land. We benefitted 3 ways....*
   *—unfinished lumber is about 30% heavier...*
   *(e.g. a 2 X 4 measures 2 1/8" X 4¼" NOT 1 7/8" X 3 5/8" as when planned)...why waste?*
   *—it cost us only 2/3 the price of finished stock.*
   *—we were able to supervise the sawing...specify exact lengths at no penalty...minimize scrap.*

**A note on green lumber...forget the BS. on kiln-drying... that's a company trick to reduce freight costs...old-timers say most of the sap is out in 6-8 wks...be sure to stack lumber properly...allowing air to reach all surfaces....*



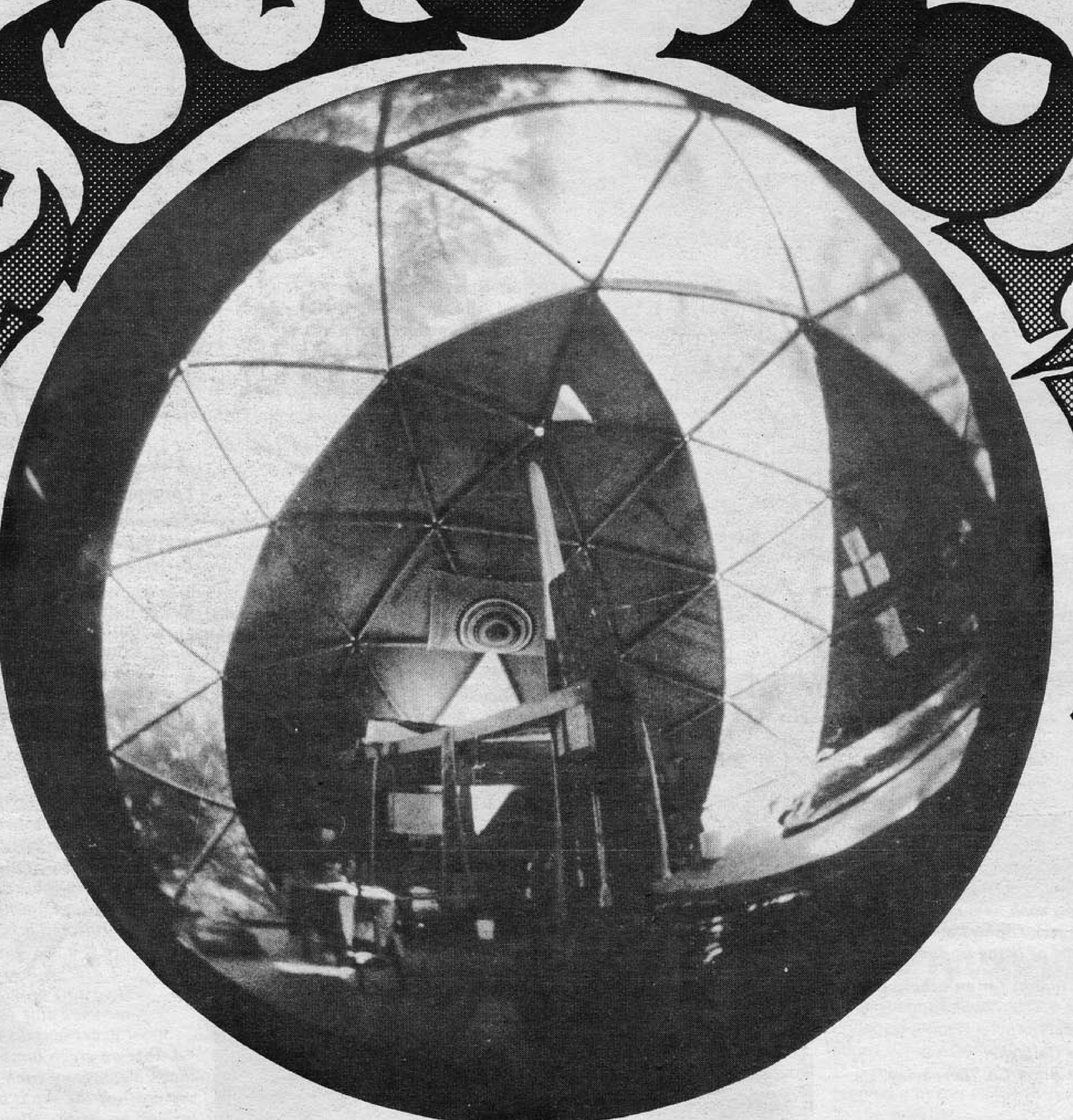

*don't stack lumber right on the ground...don't cover it.*

6. *In snow country, ask a farmer or hunter about hedgehogs(porcupines)...if you are likely to encounter any* don't use plywood *or else cover any exposed plywood with galv. wire screen. In winter, porcupines eat plywood for the salt in the glue. (Vehicle tires are similarly imperiled if local road crews spread salt)Believe it or not! We didn't.*
7. *We stored our bolts, nuts and washers in advance with a liberal coat of motor oil overall. A good move.*
8. *Cold weather domes need insulation(so what else is new?). Don't skimp on it! Especially at the top of the dome and under the floor. Urethane is a natural for these jobs...we couldn't afford it and found fiberglas a poor substitute. Any ideas on cheap, home-brew foam rigs?*
9. *Polystyrene(tradename: Safe-t-vue) makes excellent windows especially where overhead glass poses a potential threat(cheaper than glass...cut by hand). Caution: Cold-weather applications demand close attention to unusual shrinkage characteristics outlined on labels...also it scratches easily.*

A word to the Domebook—
*...thanks..*
*...technical dope on Big Sur Dome(angles, no. of pieces, etc.) is all fouled up...'spose you know that by now.*
*...don't really know about a dome this size from those plans...it stands, but...how about a freq./diameter/ recommendation chart next time.*
*...looking forward to* Domebook II.

*Joel Nagy*
*(Lorli, Mike, Marc, Margot and friends)*
*So. Newbury, N. Hampshire*

# PACIFIC DOMES

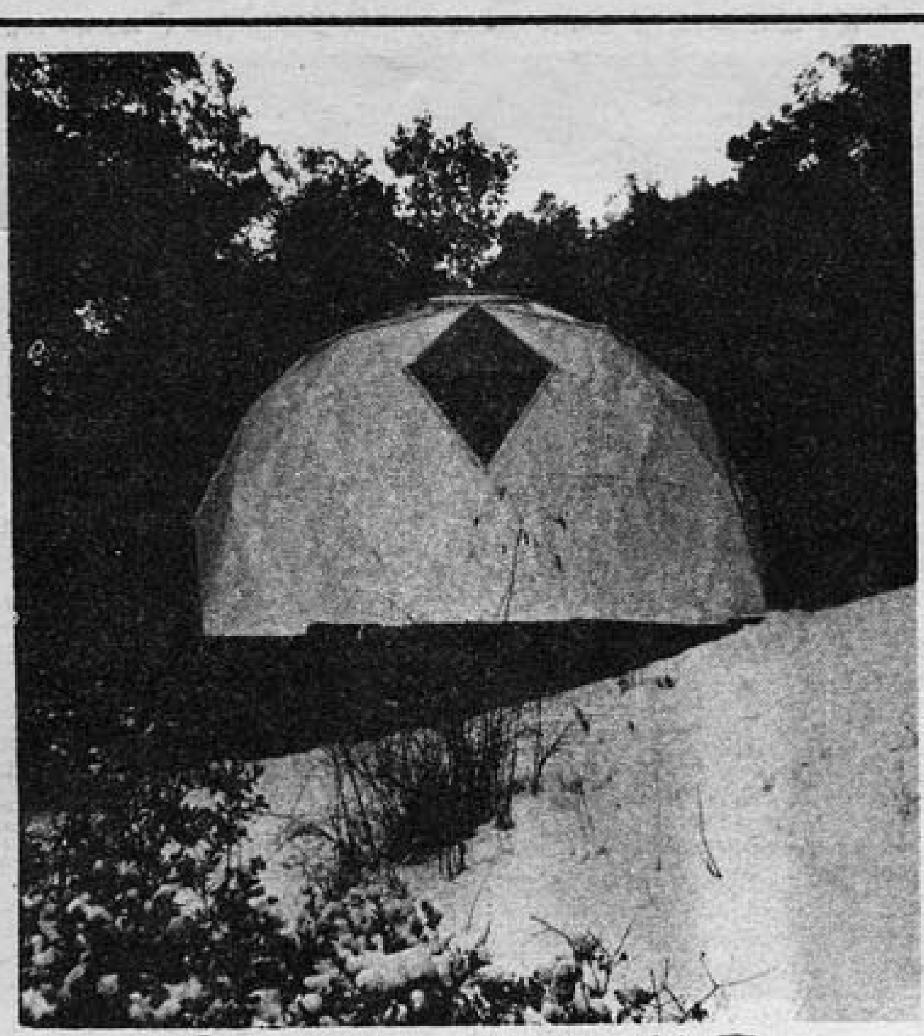


These were the first domes we built for housing in our community. We built seven in about three months. Most of those on our building crew were 15-17 years old.

With the first three domes, we were relatively conservative in number of windows and window patterns. Then kids, building their first dome, made a long sweeping arc of windows, placed to follow the path of the winter sun. Next Chris, building his dome under a large oak tree, made this double arc; when you're in the dome, you feel as if you're still half outside.

We used pipe-section hubs and stainless steel straps for the framework—a system designed by Jeffrey Lindsay and used by Fletcher Pence in the Virgin Islands about 10 years ago. The skeleton framework is first strapped into place, a membrane is then attached, and joints are waterproofed. We've had serious leakage problems with half these domes, due to a combination of improper joint design, funky workmanship, and faulty caulk. Before you try a dome like this read carefully the section on sealing.

Although all seven domes are the same size and the same geometry, placement and patterns of light, and divisions of interior space makes each one feel totally different.



# PACIFIC DOME

### VITAL STATISTICS

Geometry: 3-frequency geodesic, 5/8 sphere, icosa-alternate breakdown, vertex zenith

Diameter: 24′

Weight: (not including floor) 2050 lbs

Volume: about 4400 cubic feet

Floor area: (not including lofts) 452 sq ft

*Note:* volume is a far better measure of living space, especially in a dome, as you'll not be confined to the floor area.

Date built: 7 domes, fall and winter, 1968, in California hills

### DOME INGREDIENTS

–12 pieces 4′ x 7′ plywood for small triangles
–24 pieces 4′ x 8′ plywood for large triangles
–6 pieces 4′ x 9′ plywood for extra-large triangles } subtract for windows. You can also use galvanized steel or aluminum.
–about 750 lineal feet 2 x 3's for struts (of 8′ and 10′ lengths). Figure the proper number of each to order.
–61 hubs, cut from sections of pipe
–about 500′ stainless steel strap, about 400 stainless steel buckles
–about 20 lbs 4d or 6d hot dip galvanized nails
–quantity of window material up to you
–12 tubes of caulk
–2 1/2 gallons primer, 2 1/2 gallons finish coat paint
–misc. materials for vent, door, etc.
–floor materials not included
–35 sheets 4′ X 8′ X 1″ Dorvon insulation foam

### Type of materials we used

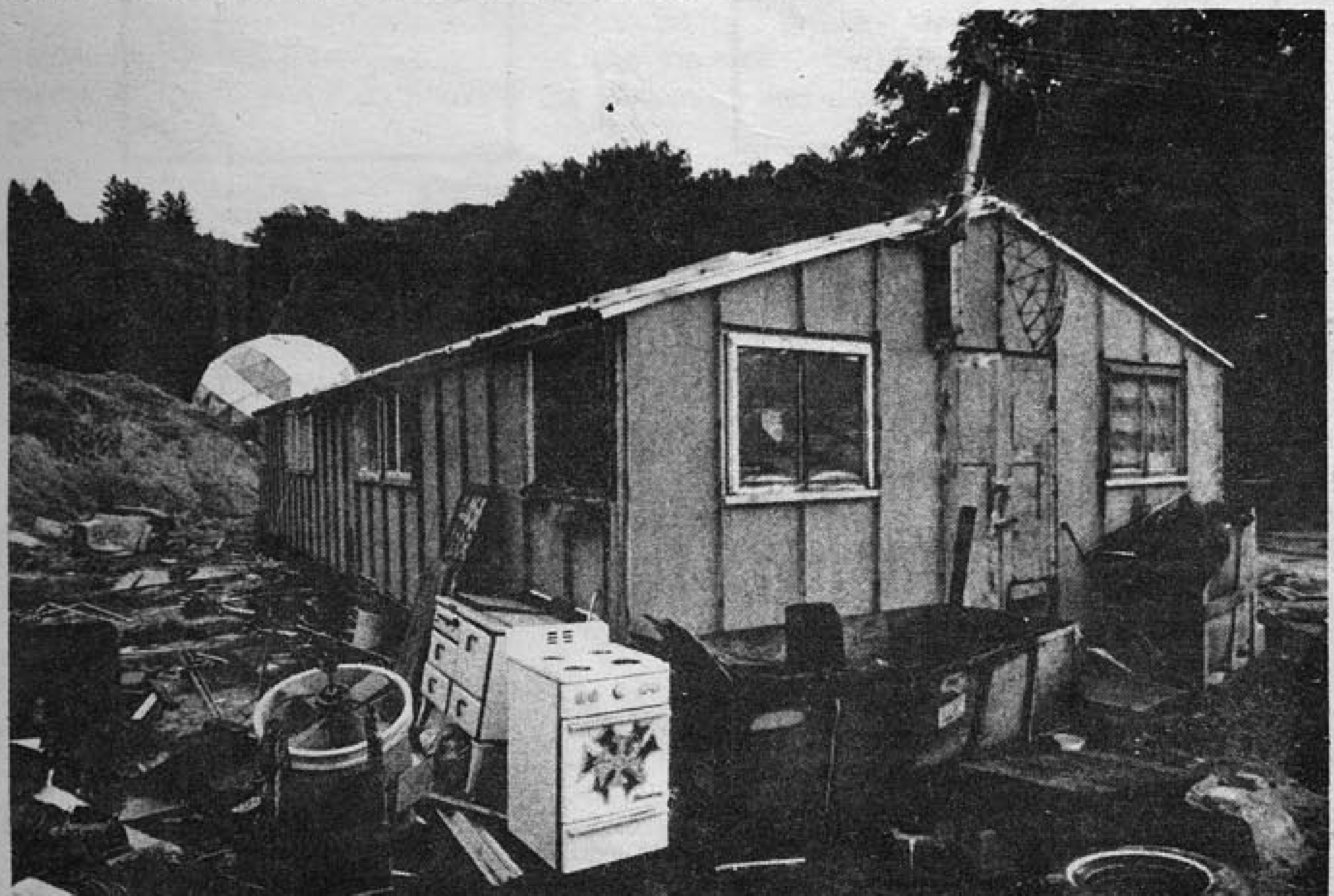
*Struts:* kiln dried 2″ x 3″ douglas fir without large knots. You don't need clear lumber, but there should not be knots that will be structurally weak. Kiln dried wood is about twice the cost of green wood. We used it because it will not shrink once in place. However, reasonably dry lumber will do. The difficulty here is shrinkage causing distortion causing leaks.

*Plywood:* U. S. Plywood "Duraply" is the only plywood I know of that has a life-time (of the building) guarantee to not de-laminate, etc. It is impregnated with resin and surfaced with a waterproof paper designed for paint application and waterproofing. Any other plywood will not hold up to direct sun exposure for any length of time, so this type should be used unless you are going to cover the exterior with something other than paint–such as sprayed-on fiberglass, or shingles.

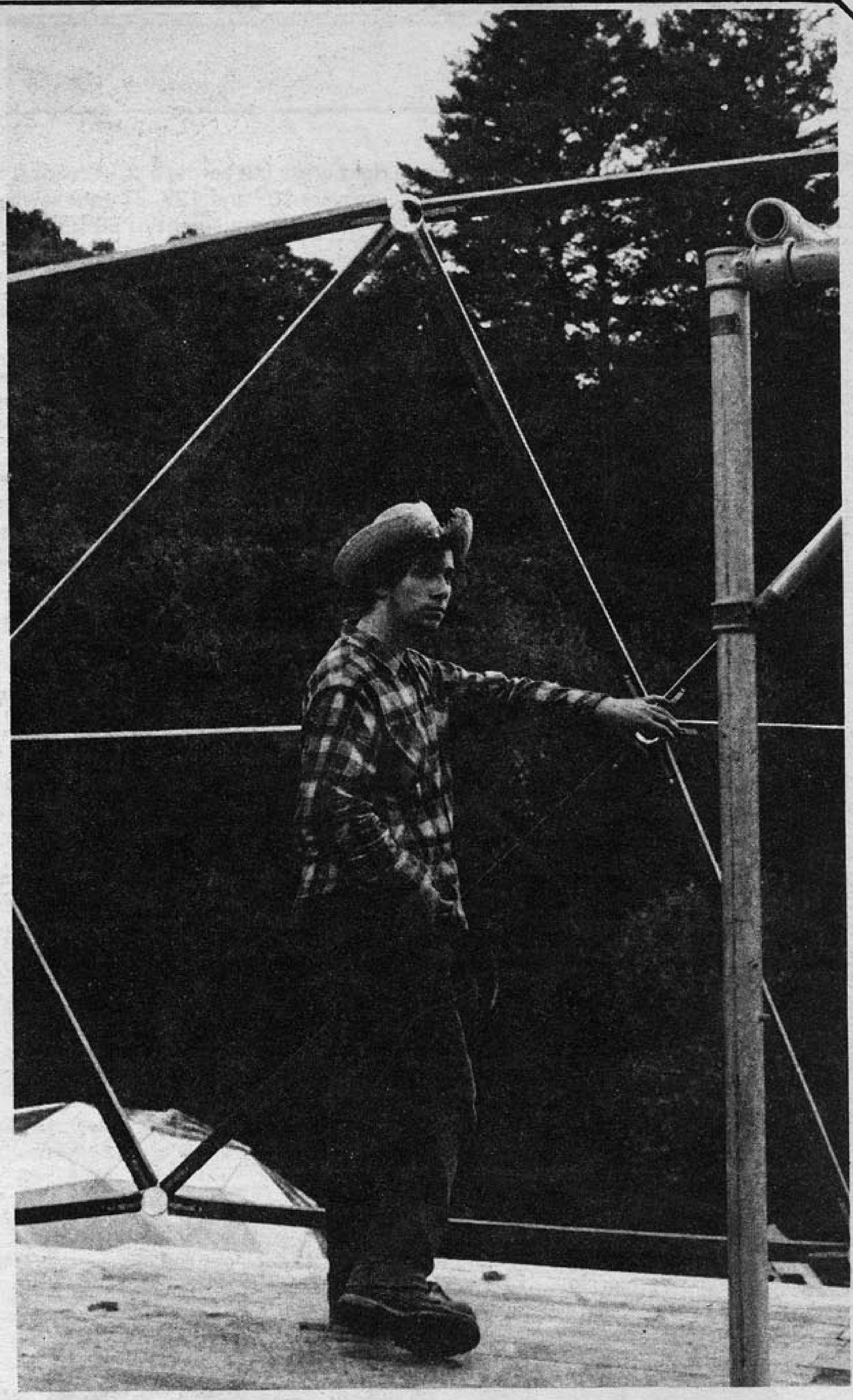
*Hubs:* we got some 10 lengths of 3, 1/2″ (outside diameter) 1/2″ wall aluminum pipe from a surplus yard, cut it on a band saw into 2 1/4″ lengths, filed down the edges so pipe wouldn't cut into strap or hands.

*Straps and Strapping Device:* If you can get the strapping tools, and have access to a drill press for drilling struts, this is a simple and quick way to frame. The 1/2″ straps and buckles are stainless steel which does not corrode. If you get a strapper, there will be instructions on strapping technique with it.

*Nails:* use hot dip galvanized nails. Electro-galvanized nails rust badly.



The Shop at Pacific.



### BUILDER'S INSTRUCTIONS

**Cutting Struts:** You need either a radial arm saw or much patience and care. A radial arm saw allows you to cut all pieces exactly the same length.

*General instructions on cutting*

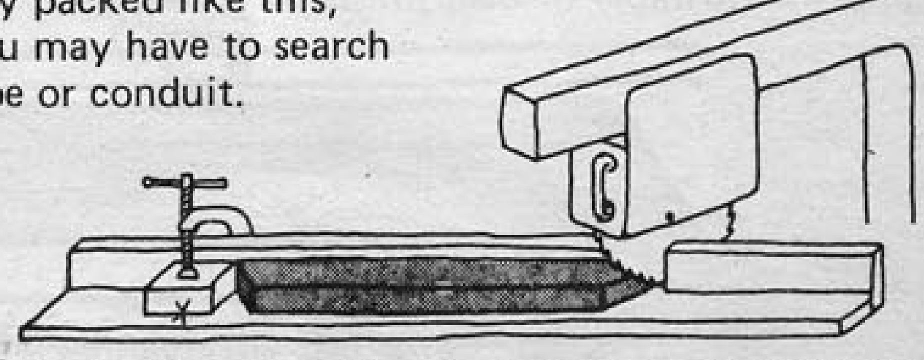
1–First cut boards in half for easier handling.
2–Check carefully the first one you cut at a new setting; the length with a tape measure, the angle with a protractor. If it is perfect, then cut the rest.
3–About every 10 cuts, check stop-table mark. The stop tends to creep along the table as the wood bumps it.
4–Sweep sawdust off table frequently. It tends to collect along fence and against stop.
5–Make some extras of each length just in case.
6–Saw smoothly and slowly.
7–Wear goggles.

**Table of struts:** make a large, clear copy of this and post by the saw.

| Strut | Number to cut | Length, using 2 5/8″ diameter hubs * | Axial Angle both ends | Angle at which you set radial saw |
|---|---|---|---|---|
| A | 30 | 47 9/16″″ | 80° | 10° |
| B | 55 | 55 15/32″ | 78° | 12° *Check shop yoga* |
| C | **80** | 56 3/4″ | 78° | 12° |

Strut lengths here are based on 2 5/8″ outside diameter hubs. This diameter is determined by tight packing of six struts of 1½″ width (Actual measurements of a 2″ X 4″ are 1½″ X 3½″). In our first domes, however, we used surplus 3½″outside diameter pipe which allowed the struts to slip around; when tightly packed like this, the dome will be much stronger. You may have to search around to find the right diameter pipe or conduit.

Radial saw



*Angle:* use an adjustable protractor to double check the saw's gauge. Hold it against fence, pull blade out and check to see that blade parallels protractor.

*Length:* tape measures are made to hook over a piece of wood. For greater accuracy, use the 1″ line on the tape measure and line it up with inside of saw blade. Add 1″ to total measurement when setting stop. V-mark stop and table and check the stop for slipping periodically while sawing.

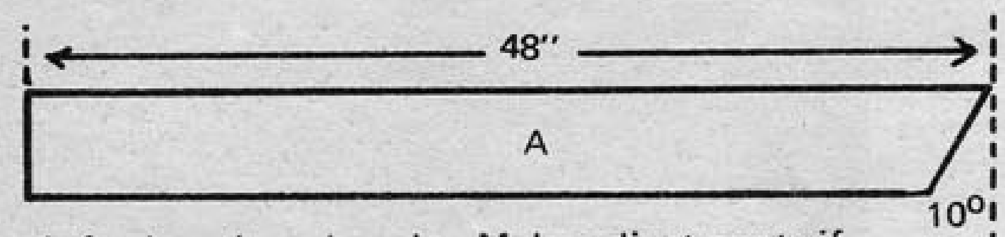
Make sure table and fence are made of clear straight wood. Close one eye and sight down the fence.

## PACIFIC DOME
*continued*

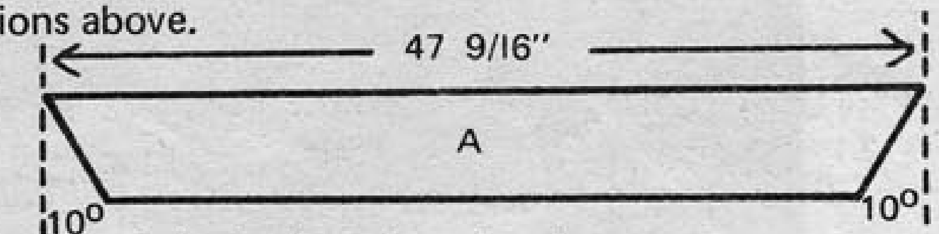
### Shop Yoga

Our radial arm saw's gauge was such that a right angle cut across a strut reads $0^{\circ}$ on the gauge. Therefore, the settings for the cuts were $10^{\circ}$ and $12^{\circ}$. If your saw's gauge reads $90^{\circ}$ for a right angle cut, angle you cut will be complement of $90^{\circ}$. That is, $80^{\circ}$ instead of $10^{\circ}$, etc.

**CUTTING A's**




**First cut:** (in half)
Set stop at 48"
Set angle at $10^{\circ}$
Cut first one and check for length and angle. Make adjustments if necessary and go ahead on the rest.
Follow general instructions above.
Stack




**Second cut:** (to length)
Set stop at 47 9/16"
Leave angle at $10^{\circ}$
Cut first one. Check very carefully for length and angle.
Continue as above.

**Color code:** Stack them in a neat pile; spray-paint tips of each end red.

**CUTTING B's**

**First cut:** (in half)
Set stop at 60"
Set angle at $12^{\circ}$
Cut first one and check for length and angle. If o.k., cut the rest.
Stack

**Second cut:** (to length)
Set stop at 55 1/2"
Leave angle at $12^{\circ}$
Cut the first one. Check carefully for length. If o.k., cut the rest.

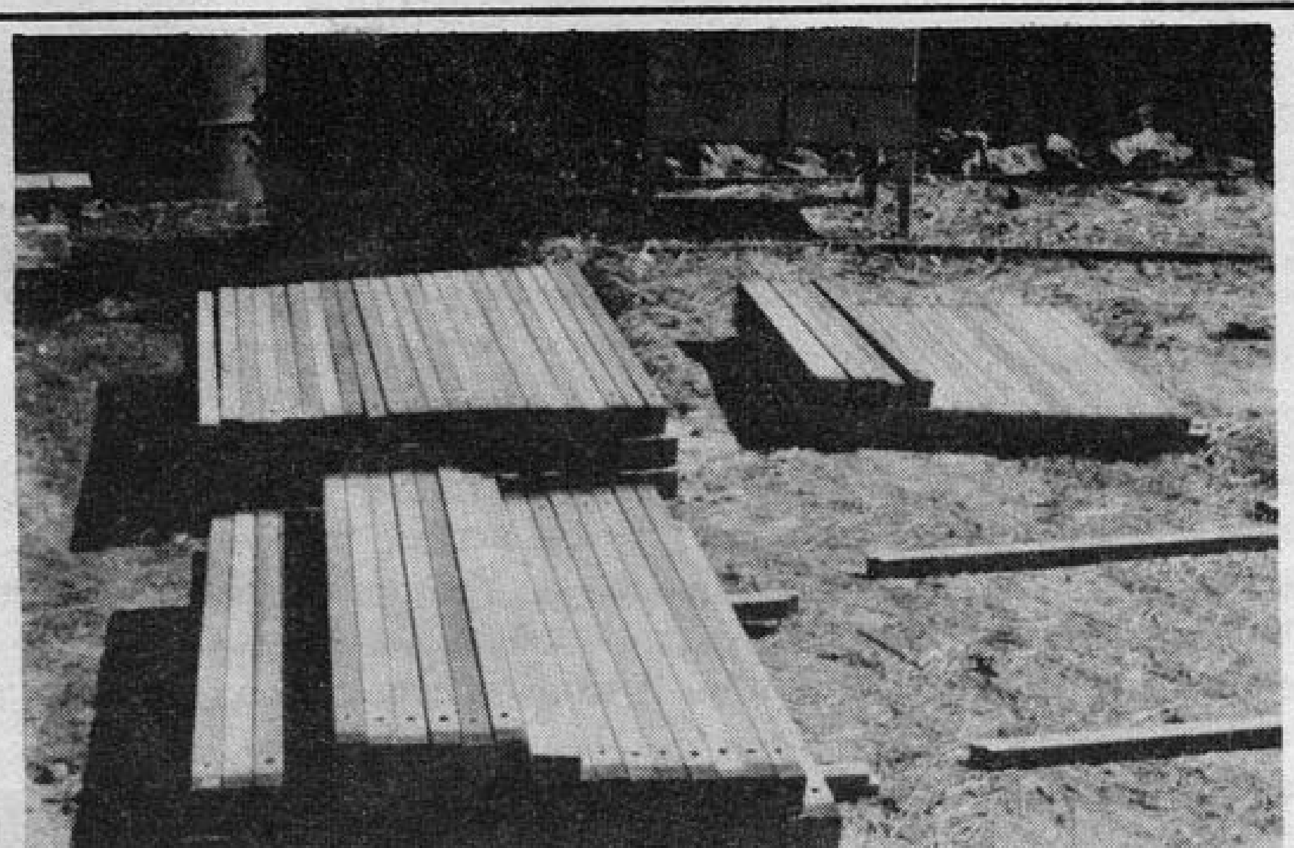
**Color code:** Spray-paint tips of both ends blue.

**CUTTING C's**

**First cut:** (in half)
Set stop at 60"
Leave angle at $12^{\circ}$
Cut first one and check for length. If o.k., cut the rest.
Stack

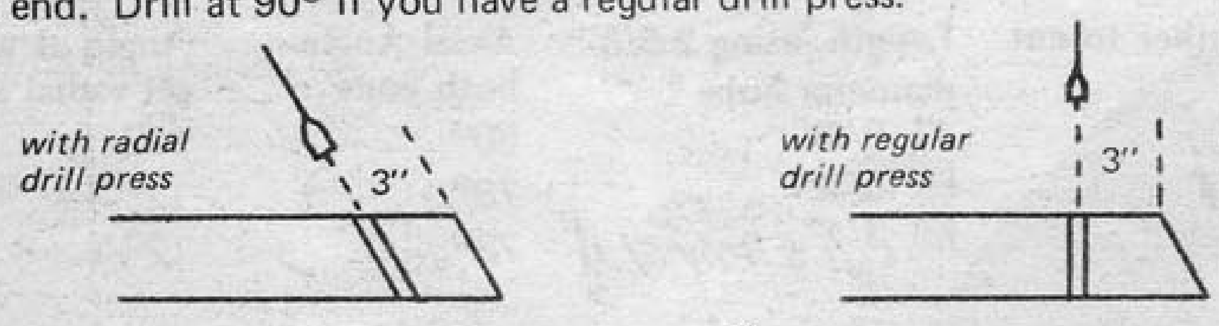
**Second cut:** (to length)
Set stop at 56 3/4"
Leave angle at $12^{\circ}$
Cut first one. Check length carefully. If o.k., cut the rest.

**Color code:** Spray-paint tips of both ends yellow.

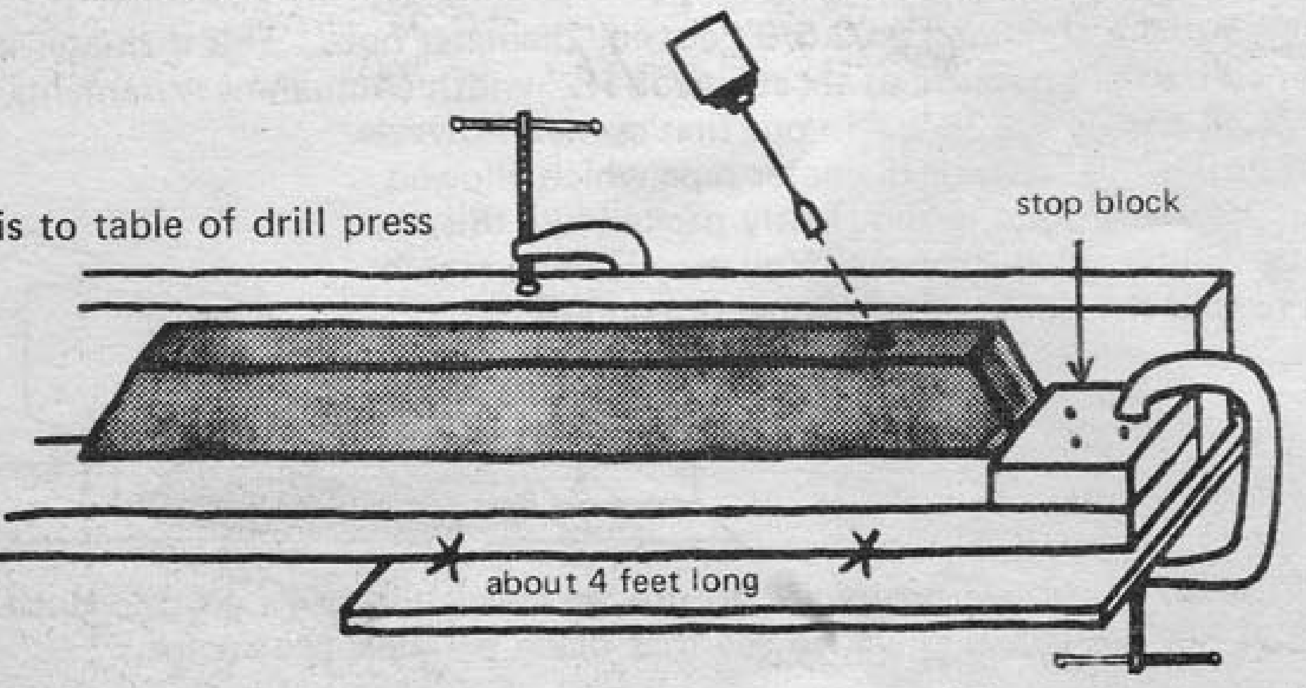


### Drilling Struts

It is essential that the hole be drilled very accurately, so use a drill press. The hole must be centered, and if you have a radial drill press, drilled at the same angle as the strut end. Drill at $90^{\circ}$ if you have a regular drill press.




Jig:
Clamp this to table of drill press



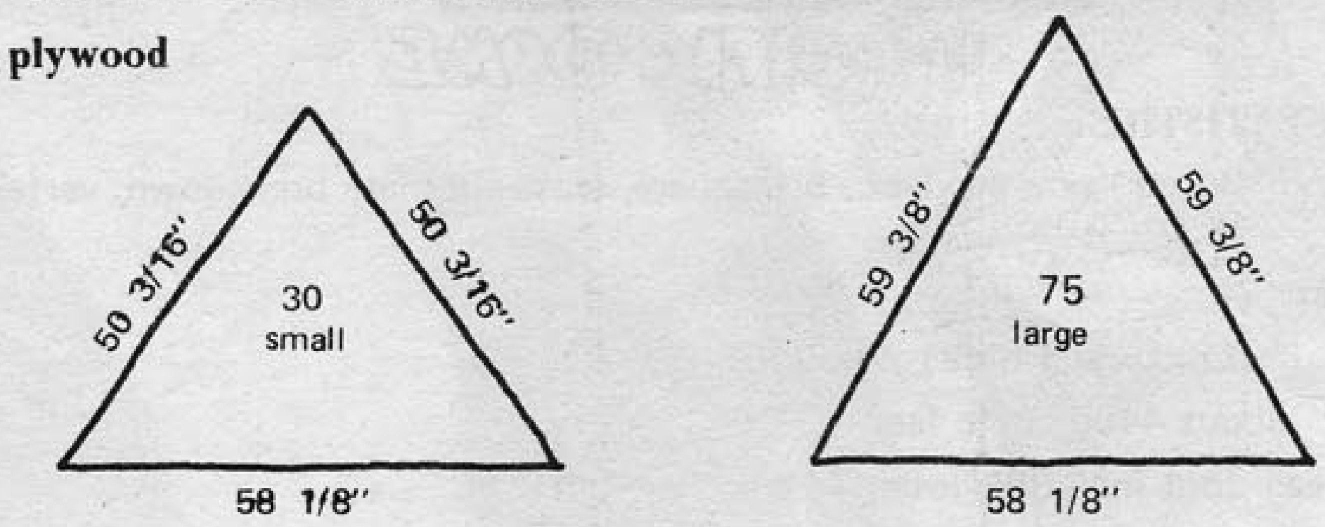

Using a paddle type blade, drill all the way through strut. Disregard minor splintering where bit breaks through.

Have a big enough block under bit so you don't drill holes in drill table.

Sweep shavings out of jig after each hole; otherwise the next strut will be out of position.

V-mark jig & table and check for slipping periodically while drilling.

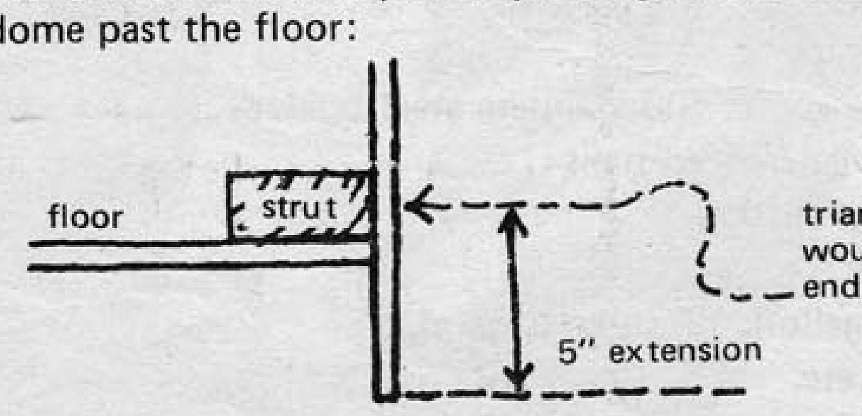
### Cutting plywood




The number of triangles above are for covering the *entire* dome with plywood. Adjust accordingly (subtract) for windows, doors.

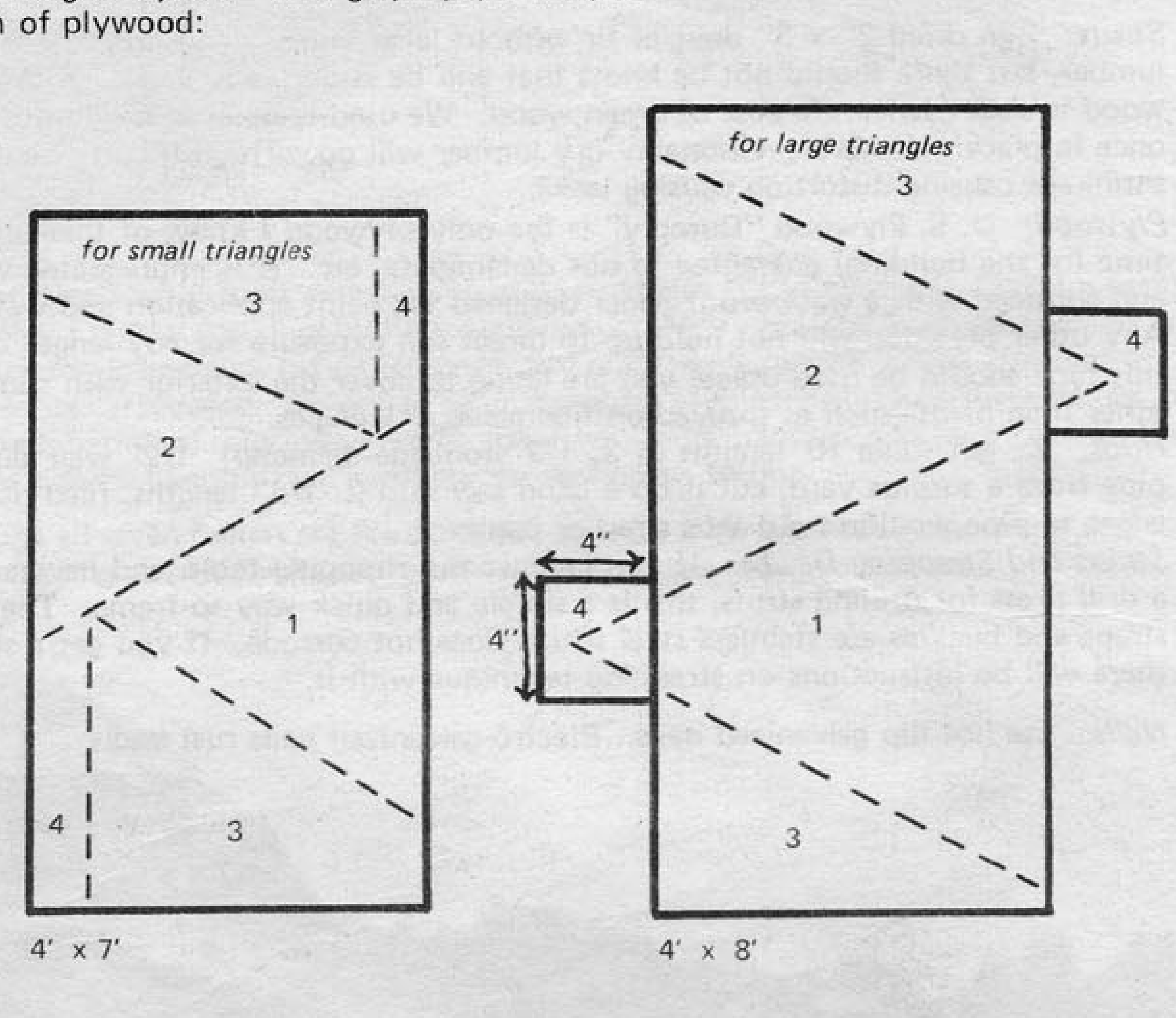
Plot on graph paper how best to utilize plywood for the size dome you are making before ordering. Find most economical way to get triangles out of rectangles. For our domes we found 4' X 8' sheets good for the large triangles, 4' X 7' sheets good for small triangles. Draw the plywood sheets on graph paper, cut out paper triangles, move them around to find the most economical arrangement.

We cut the 15 bottom course point-up triangles with 5" extensions so they let water run off the dome past the floor:



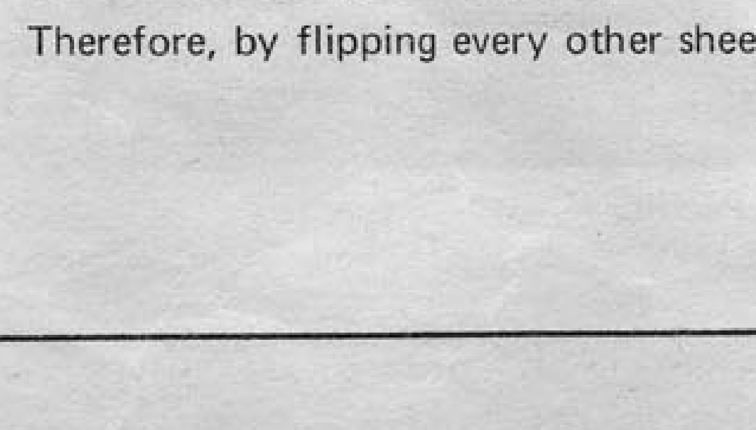

However, it might be simpler to fit in pieces of plywood here, or use flashing.

*Plywood triangles layout:* with graph paper we determined that this was the best utilization of plywood:

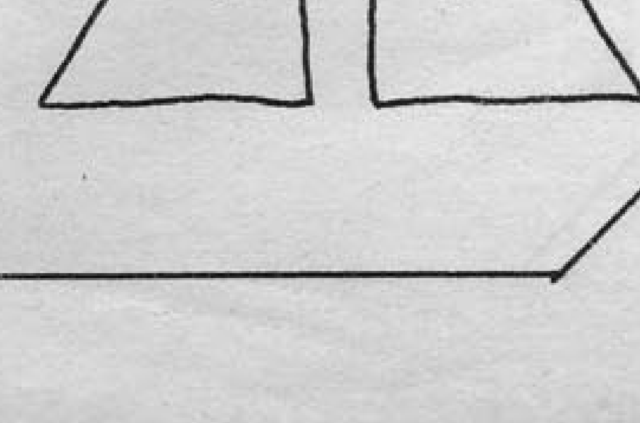



Note that you cut two whole triangles and two halves from each sheet. The halves are patched so that you get three full triangles per sheet.

If you are using "Duraply" or any other type of good-one-face plywood, you will have to flip over every other piece you cut. That is, you will cut one good side up, the next good side down. If you cut all pieces good side up, you would end up with all left side triangle halves:




Therefore, by flipping every other sheet you get:



*Cutting jig*

Setting up a jig insures that you cut each piece of wood accurately, and alike. Sometimes, especially without a lot of skilsaw experience, it's hard to follow a pencil line. A jig or a straight edge gives you something to run the skilsaw guard against.

In fig 1, "d" shows the distance from straight edge to *outside* of blade, which makes the actual plywood cut. Also, set the blade depth so it doesn't cut through the jig.

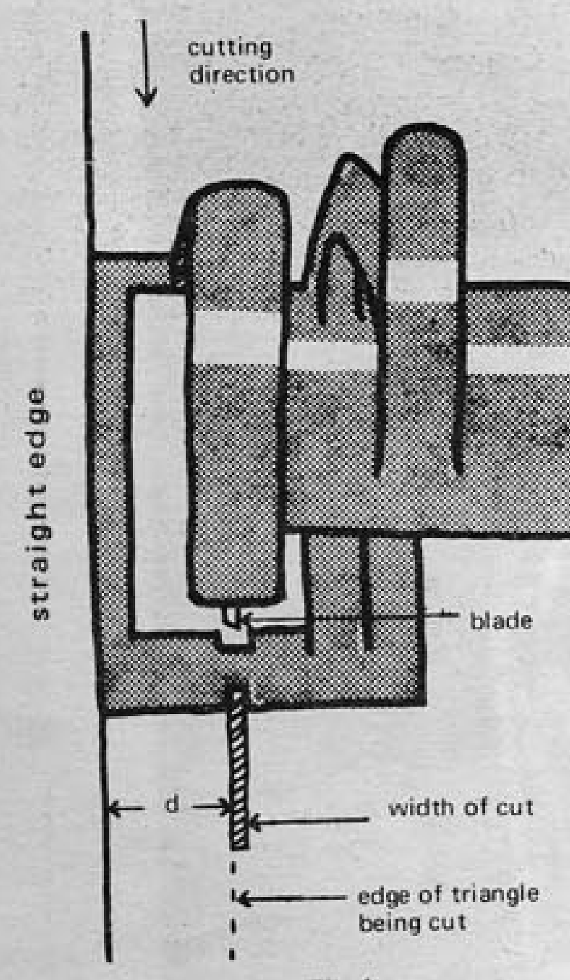



*Fig. 1*

**Simple Jig**

*Berry Hickman told me about a method they used for cutting pieces of plywood at Lama. Steve clamps a number of sheets of plywood together, using wood clamps, then skilsaws through as many thicknesses as the blade depth will allow. You can do this by eye, or rig up an aluminum strip for a straight edge that the saw guard will run along, as below in Bill's jig. When you remove the cut pieces, there will be a slight line along the next piece of plywood from the blade that you can use as a guide.*

Bill's jig:

This jig works best on a concrete floor. The stops hold the plywood snug for cutting. Make them of the same thickness as the plywood you are cutting and nail them on. Shaded area is where you flop the plywood to be cut.

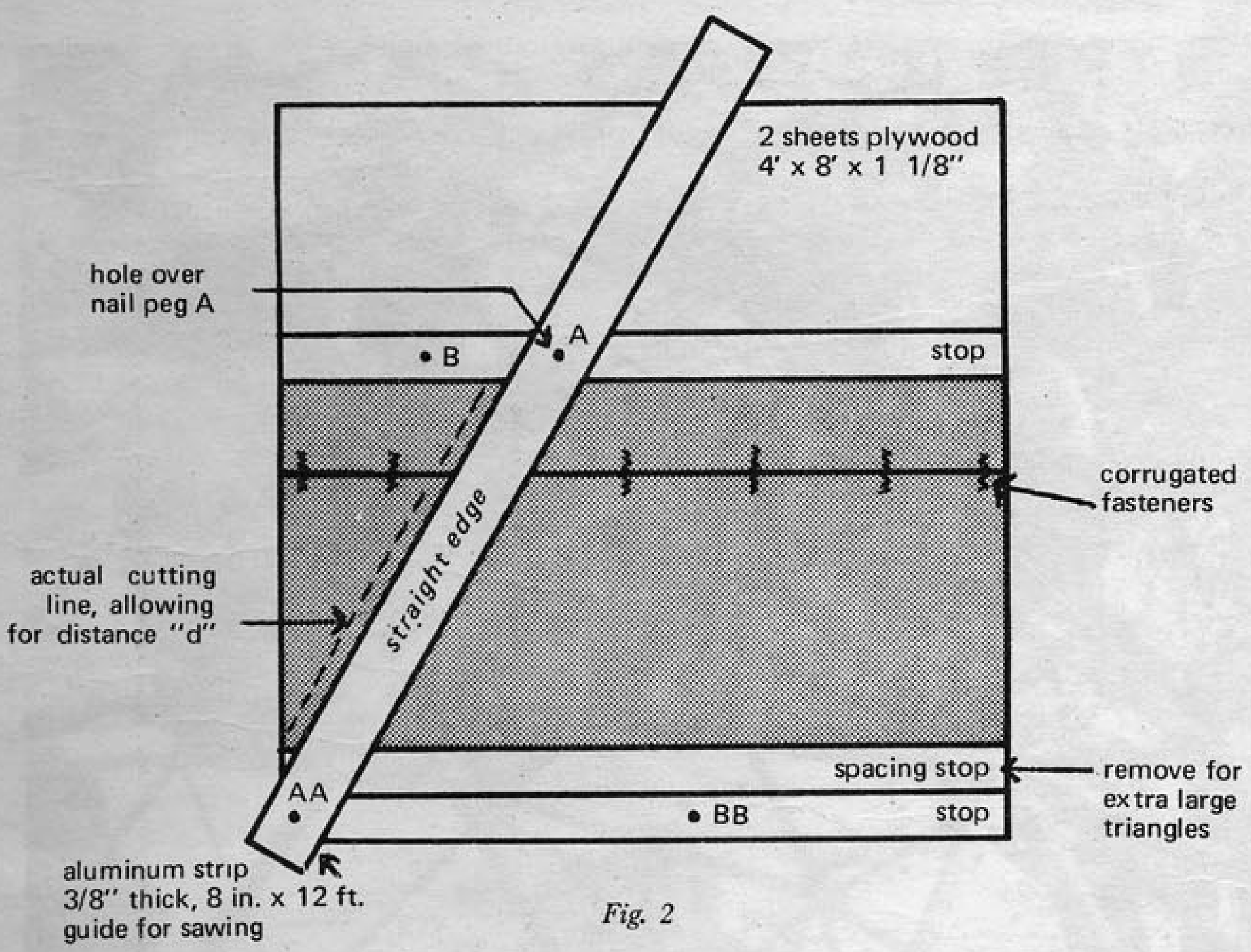



*Fig. 2*

The aluminum strip has holes in it so it can be held in place by pegs (16d nails with heads cut off) which are pounded into the stops. Carefully draw a master triangle on the jig and then position the aluminum and nails, not forgetting distance "d".

After cutting one edge, aluminum on nails A and AA (fig. 2), flip the metal onto nails B and BB and cut the other side of the triangle. (Fig. 3)

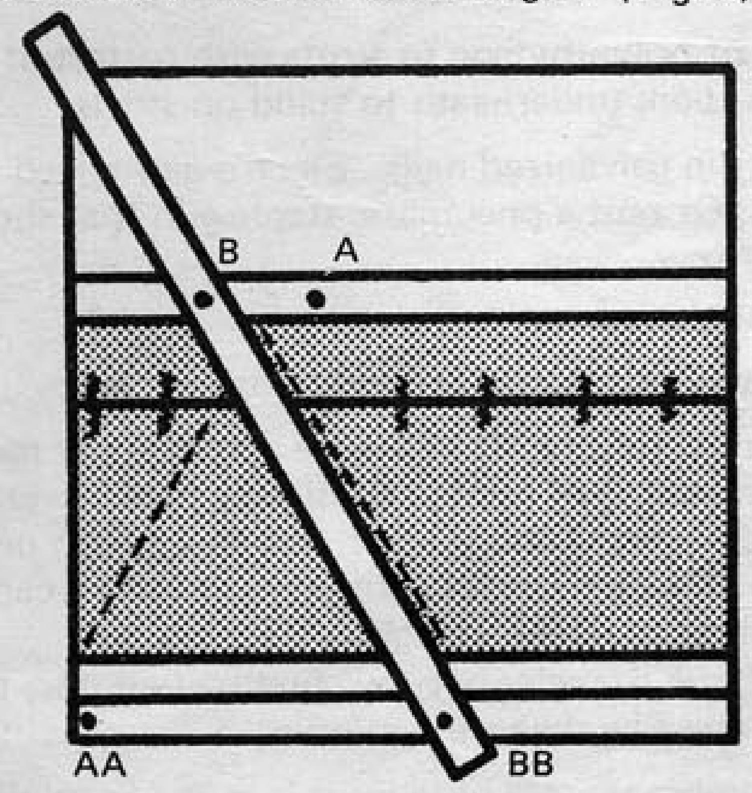
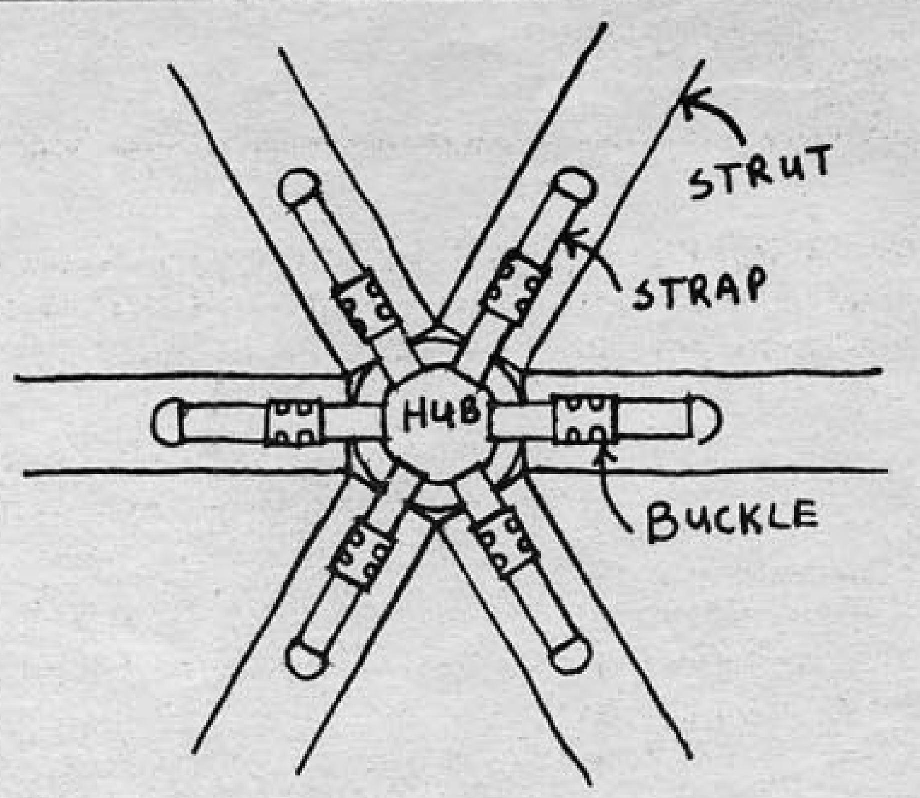



*Fig. 3*

Wear ear guards and goggles while cutting.



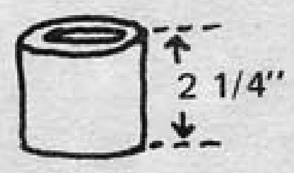

**Hubs**

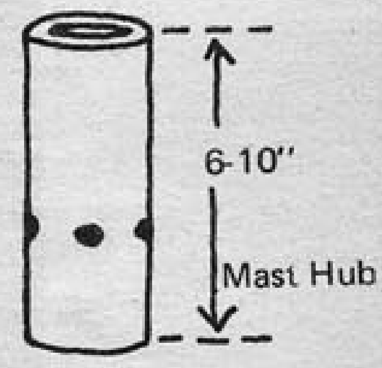
We built 3 domes with metal pipe hubs, 4 with plastic pipe hubs. The plastic hubs around the base of the domes deformed when plywood was nailed on. The advantage of the plastic hubs is that they're cheap and easy to cut—you use a hand saw. However, they'll be weak where there are large window patterns, and metal will be better if you can obtain the right size.

The best way to cut metal hubs is on a power hack saw; perhaps you can have it done in a machine shop. The inside edges should be filed off to prevent the strap from being cut by the sharp edge.

If you use different sized pipe for hubs, adjust strut size accordingly.

Cut in approximately 2 1/4" sections.




There are 60 regular hubs in this dome, and one mast hub.

The mast hub goes at the top, in center of pentagon, and is used for throwing your climbing rope over. *See p. 117 on climbing.*

Drill holes for straps.

**Strapping:** Here the cost of the strapper and crimper (about $70) was justified for us as we built several domes. Here's how to use them:

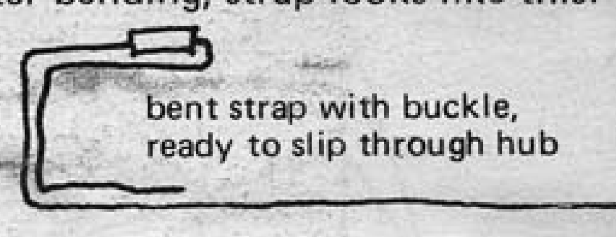
Learn to use the strapper with instructions that come with it.

Assemble prefab components on a big table with a few people helping you hold struts.

Once you determine the proper length strap you can cut a number of them.

We doubled strap where it grips the hub so the metal wouldn't cut into the strap.

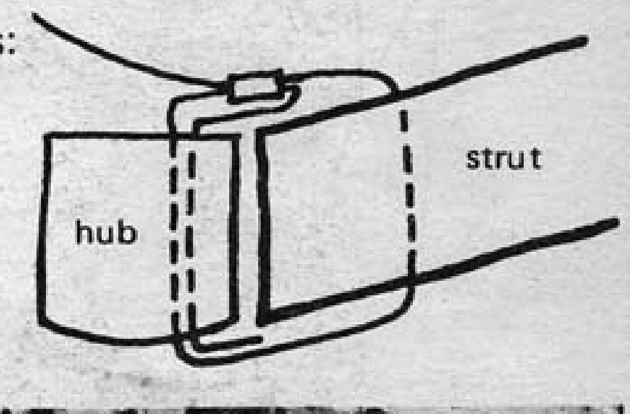
After bending, strap looks like this:



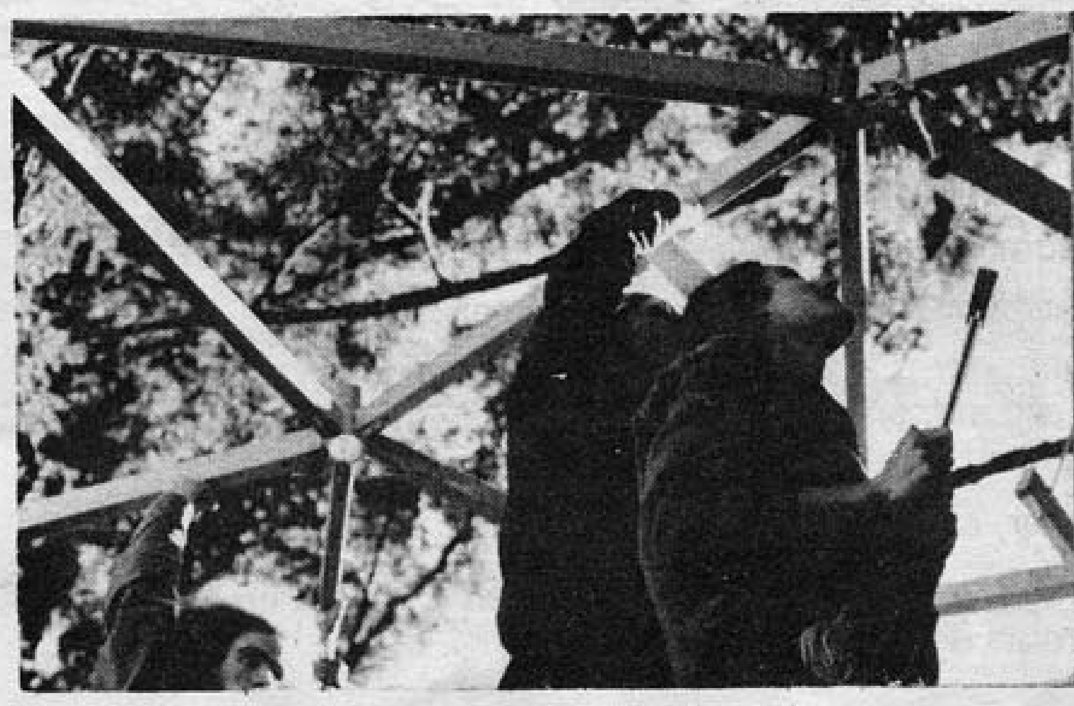

Six people work well in preassembling strut sections:

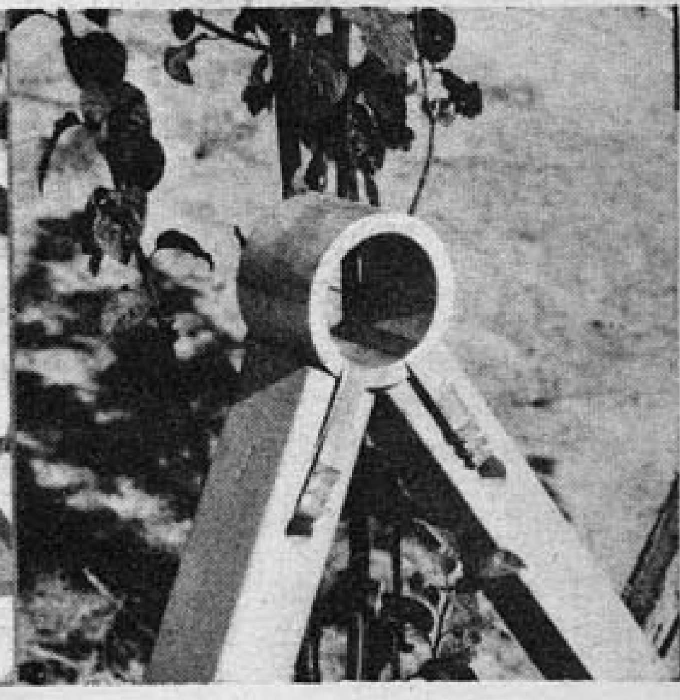
—one cuts straps
—one bending
—two assembling (putting straps, hubs and struts together)
—two strapping

This is then slipped through strut and hub like this:




Strapper is engaged.
Crank toward hole until it is tight.
Crimp buckle.
Break off end of strap by twisting strapper back and forth.





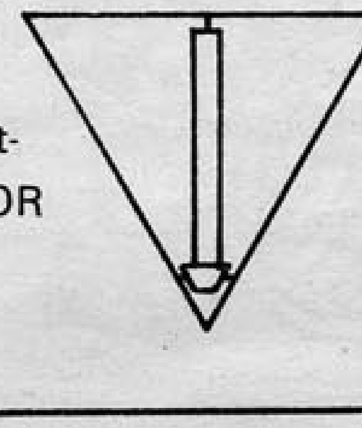
**Treating Patched Pieces and Plywood Edges**

You should also prime the edges of plywood triangles before nailing onto dome. This will prevent moisture from delaminating plywood.

The patched pieces are the worst potential trouble spots. When the dome expands and contracts, they tend to open, and consequently leak. You can do two things:

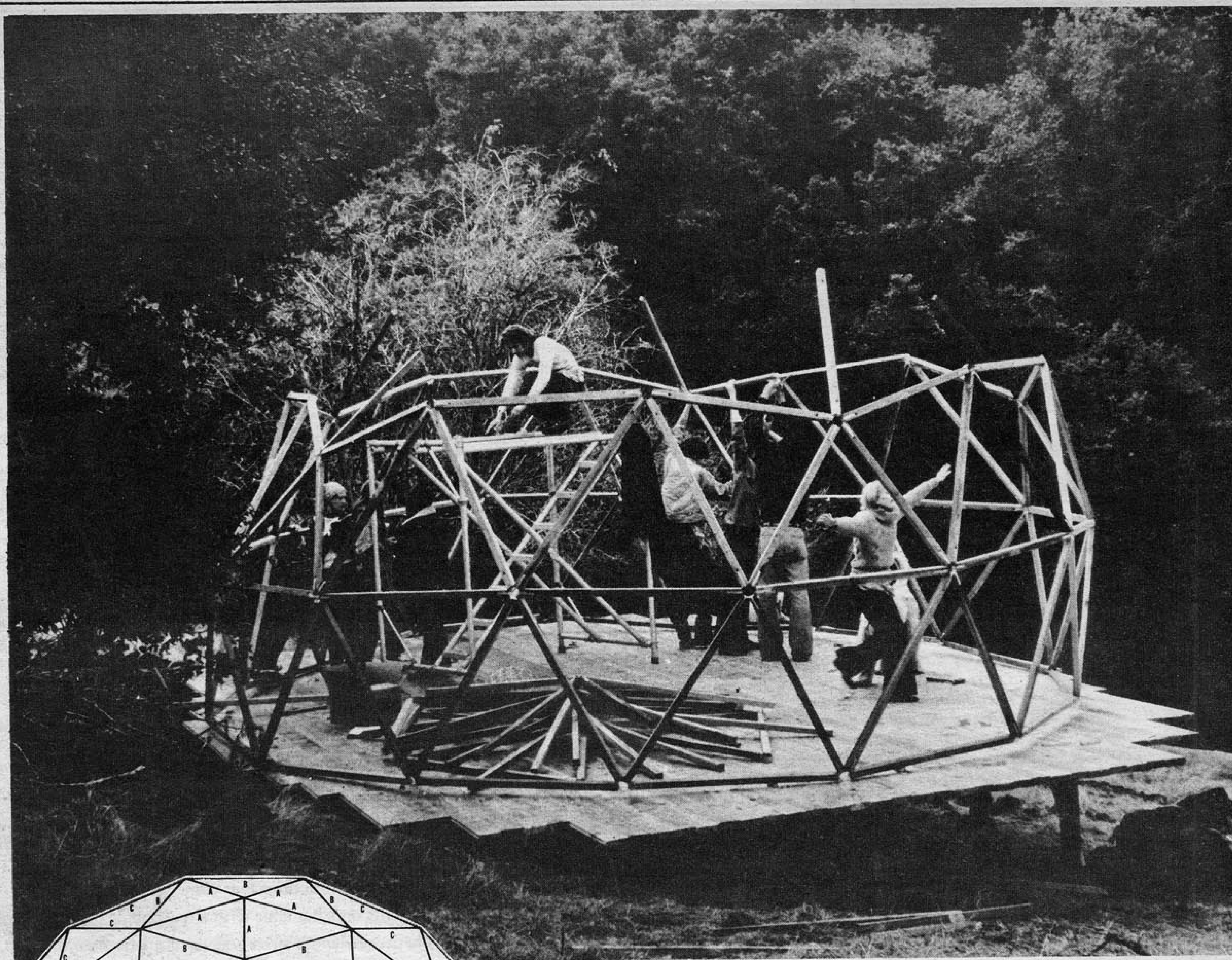
insert wood strips to nail edges to. Leave enough space for struts. Tape outside, after painting.

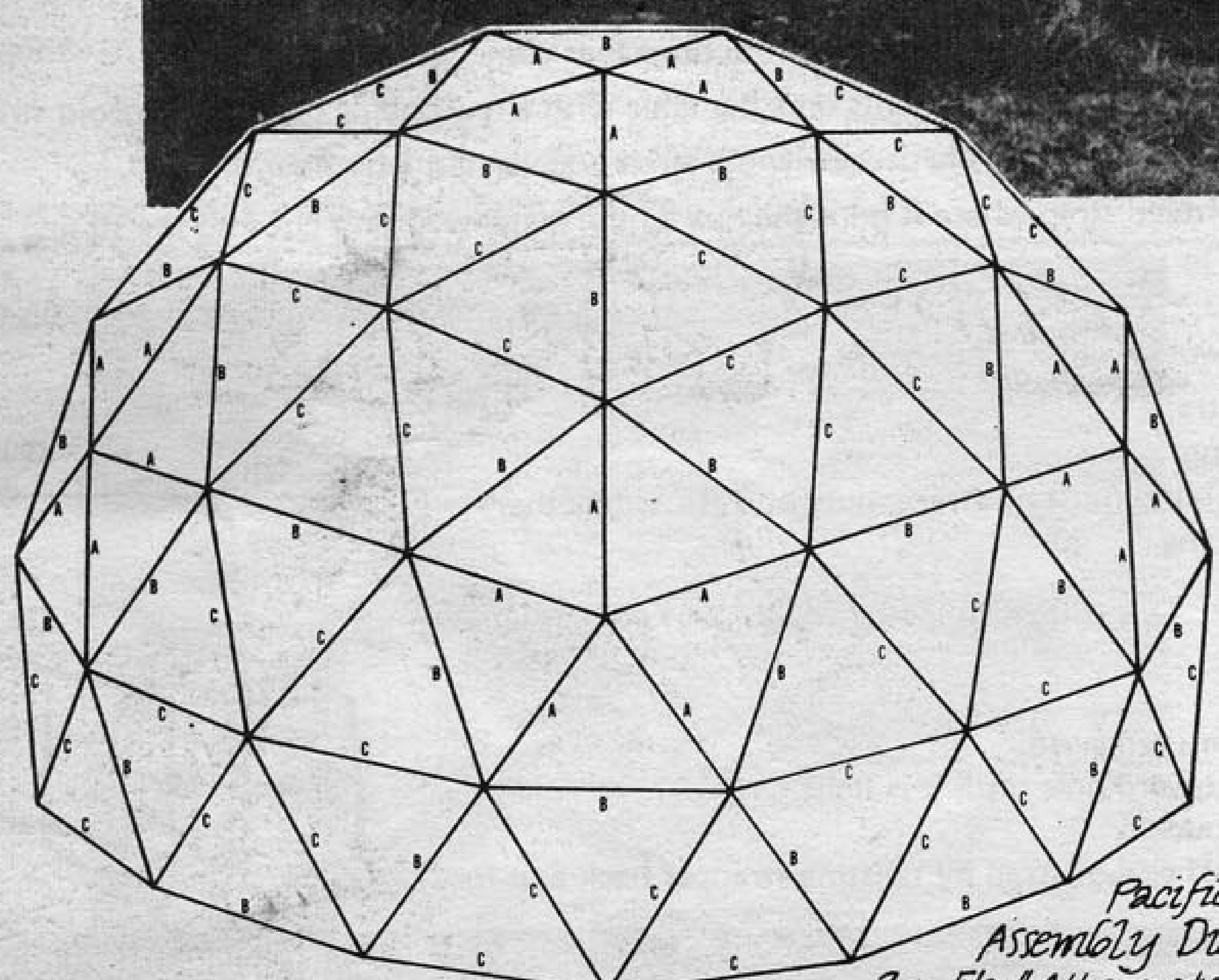
OR



fiberglass tape inside, use either fiberglass or other type tape outside, after painting.

PACIFIC DOME continued





Pacific Dome Assembly Diagram 3v 5/8 "Alternate"

## PUTTING IT UP

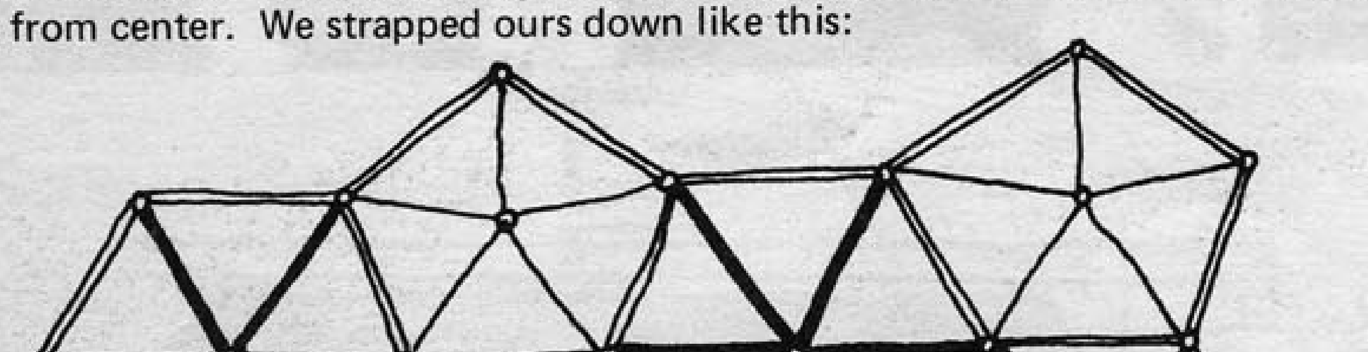
Invite friends, try to pick a nice day, have some homemade bread for when it's completed. You'll want to spend some time sitting inside after it's up.

A scaffold makes things much easier. you can rent one, with wheels.

*Set model in center.* Start at bottom course. It is best to have one person who just designates what goes where. Work around, and up. *Temporarily tie it down if there's a wind.* It will start holding itself up during the second course.

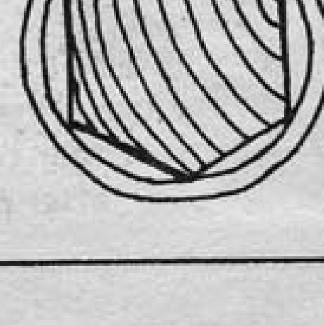
Strap as you go. One man on strapper, another working the crimper.

Next, attach to floor. Take an average from center of floor. Place each strut an equal distance from center. We strapped ours down like this:

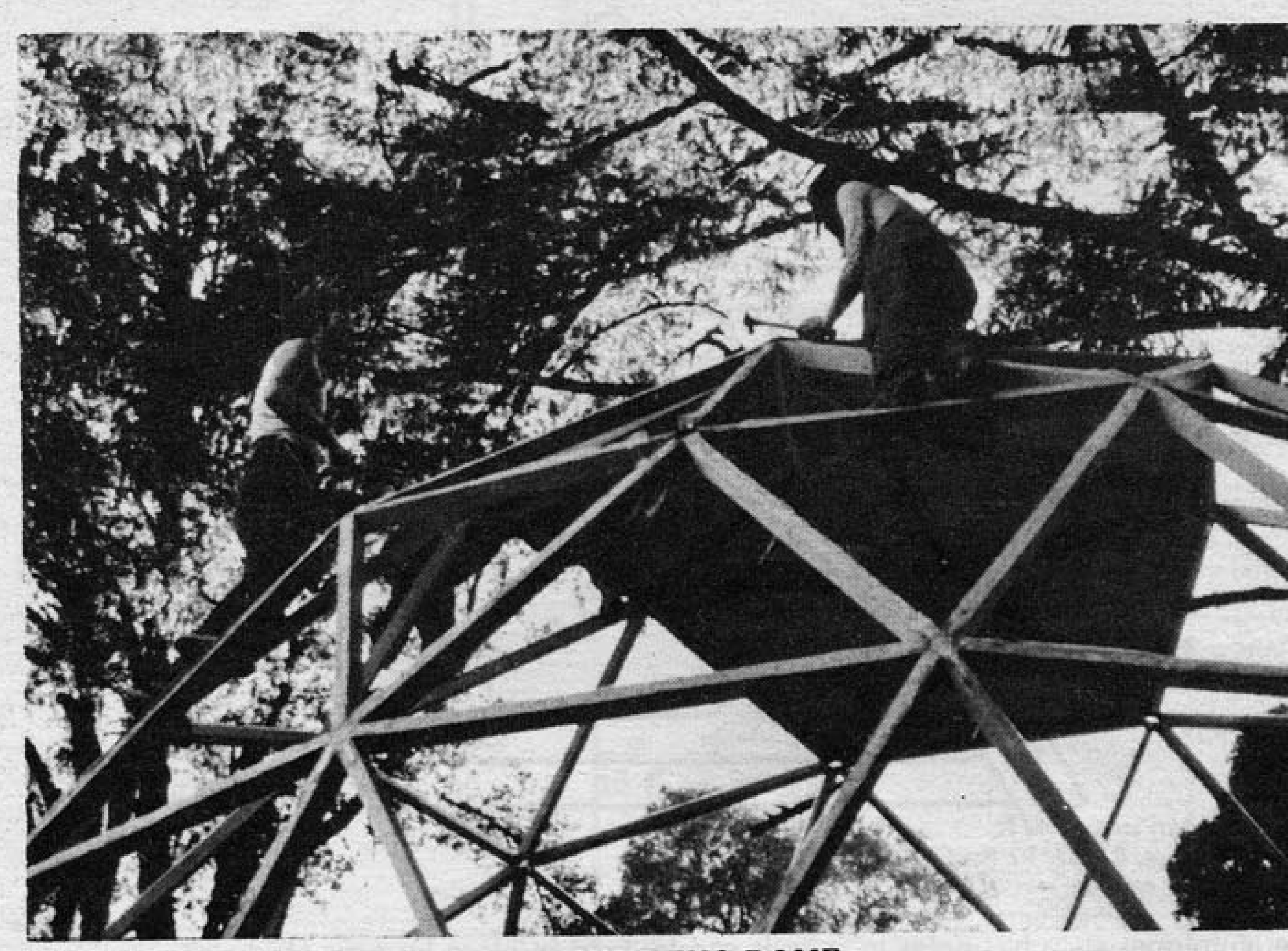



Drill holes in floor and strap each hub to floor. Strap it securely, so dome won't blow off. If you don't strap, work out a means of bolting down.

If you use plastic hubs there should be blocks inside base course hubs so weight of dome is not resting on pieces of plastic.



Cut floor off to fit dome.



## SKINNING DOME

You should wait a while, sleeping under framework, seeing where the morning sun rises and planning carefully where to admit light. This will vary according to season. When this is decided you can start with the plywood skinning. Make sure struts are equally spaced around hubs. You can do this as you go, lining up struts with marks on hubs. Be careful, as errors will accumulate.

If you caulk, staple strips of polyethylene to struts with rustproof staples. Best to start from top, as it leaves room underneath to stand on struts.

Nail triangles on with hot dip galvanized nails. Electro-galvanized nails will rust. One nail about every 4" or 6". Or rent a pneumatic staple gun that shoots rustproof staples and *be careful* of people below.

Have a helper handing triangles up to you.

The struts must be accurately positioned around hubs.

Nailing should be done very carefully. Don't leave any hammer marks on surface, as they will complicate the sealing of joints. Go slowly here. Everyone wants to nail on triangles. Two or three nailers is about right, but check each one out to make sure he is hammering well, and placing triangles carefully. We had a careless nailer on one dome and later had to custom fit some triangles.
At bottom course, where large triangles overlap, first nail on one, then a few nails to hold the overlapping one, and saw down the middle.

Calculating for interior membrane: see note on this in Big Sur dome. You will use a different radius times the chord factor for calculating interior paneling.

(See table of contents for next steps: **sealing joints; doors & windows; interiors.**)

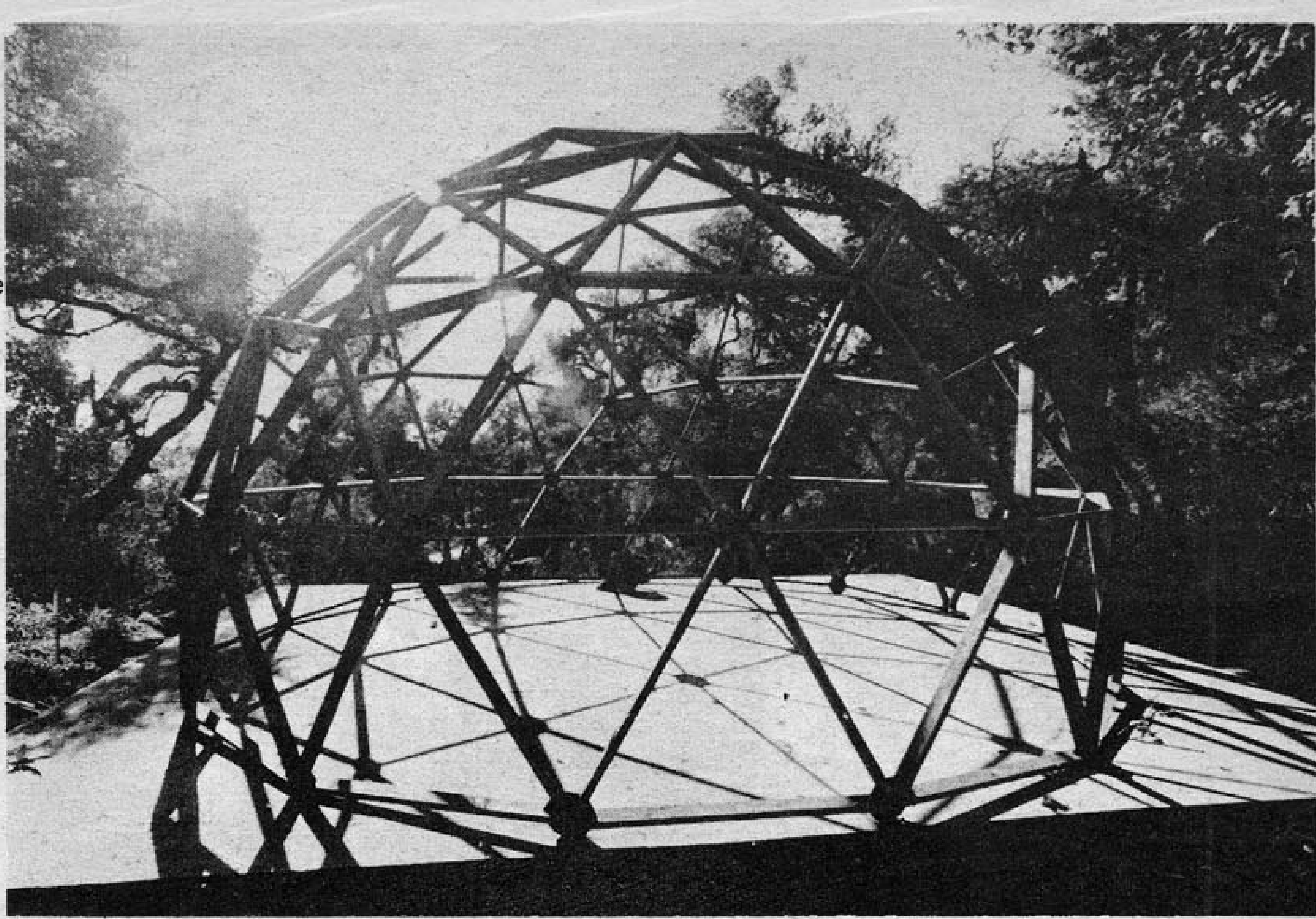
# WASHER HUB & PLYHUB

The plate and bolt hub system has been used for steel tube domes, and it seems to be a strong simple system for wood domes. See the shake dome, p. 53, where the plate is mounted on the outside surface of the struts.

Calculations and tests indicate that the plate is strongest set into a notch in the strut. A skin system (plywood or ferrocement) that must bear on the outside of the struts (unlike the shake dome) would also mean that the plate at least be on the inside of the struts. Both the washer hub and plyhub notched strut systems will build a dome that meets building code strength requirements.

For plywood domes, mitering the struts for the washer hub system would give you a continuous surface for nailing on the plywood skin.

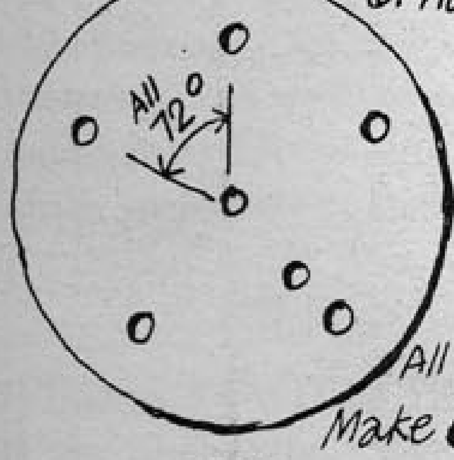
Bob Easton



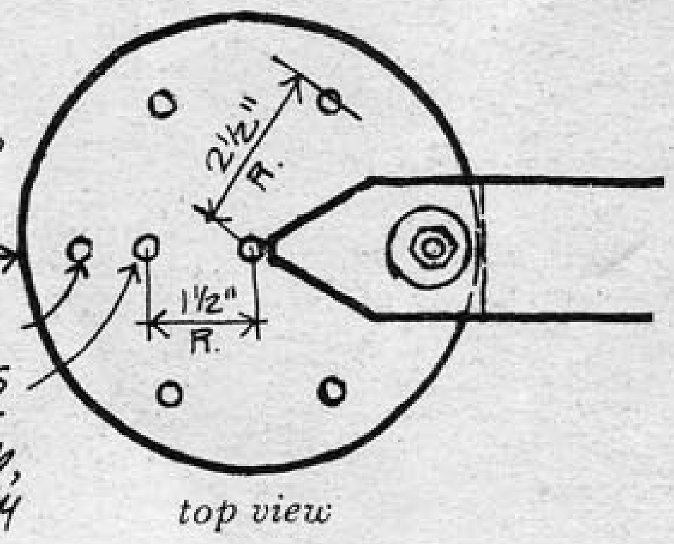
24' 3v made with old 2 x 4's and plyhubs

## Washer hub

for 5/8 3v Alternate (Pacific Dome) Make 61 hubs:



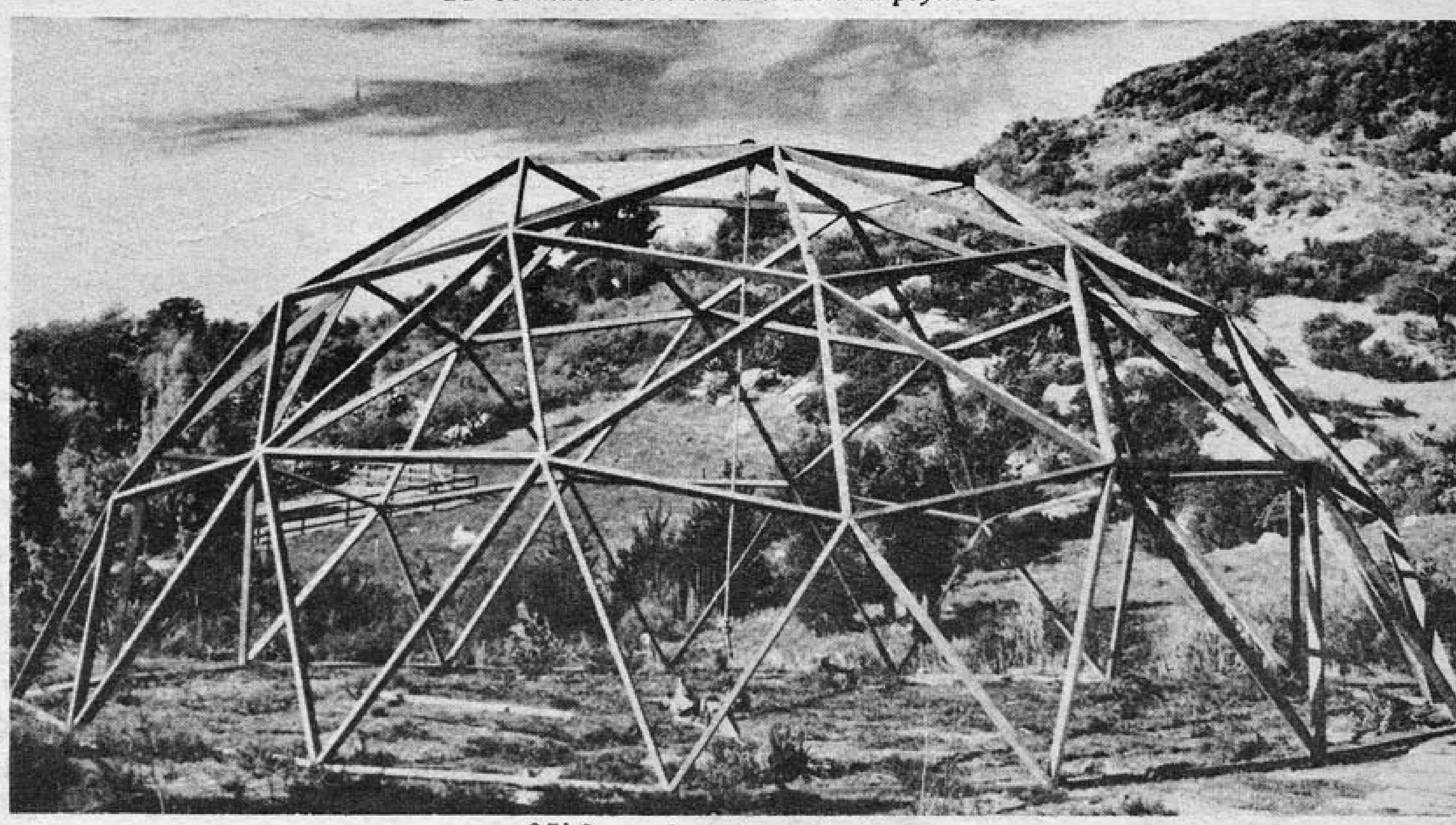

All A struts code yellow
Make 6



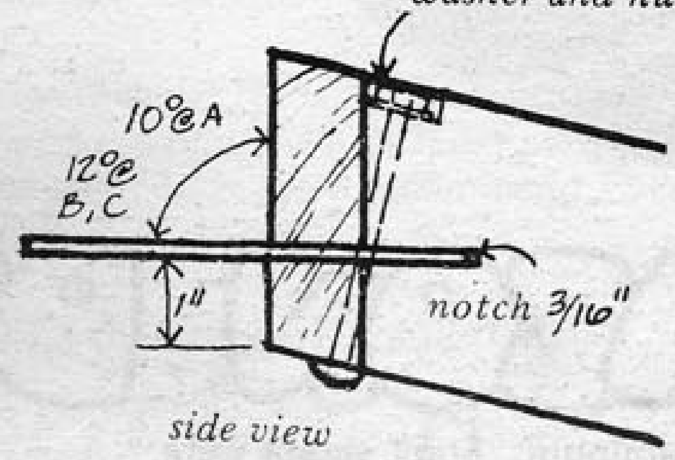

steel washerhub 6" dia.

holes make 2 holes for one strut on each hub, to stop any rotation

top view



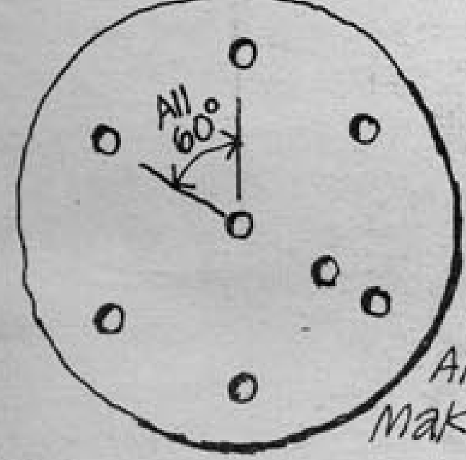
37' 3v made with washer hubs



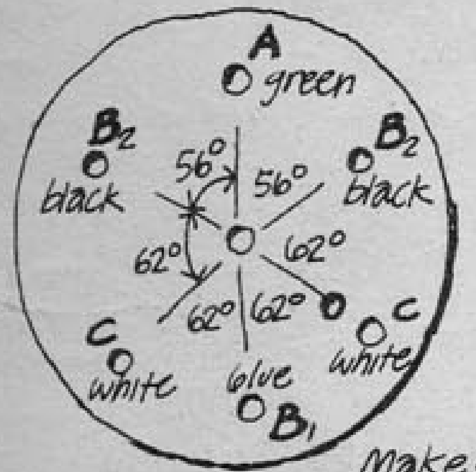

bolt with countersunk washer and nut

notch 3/16"

side view



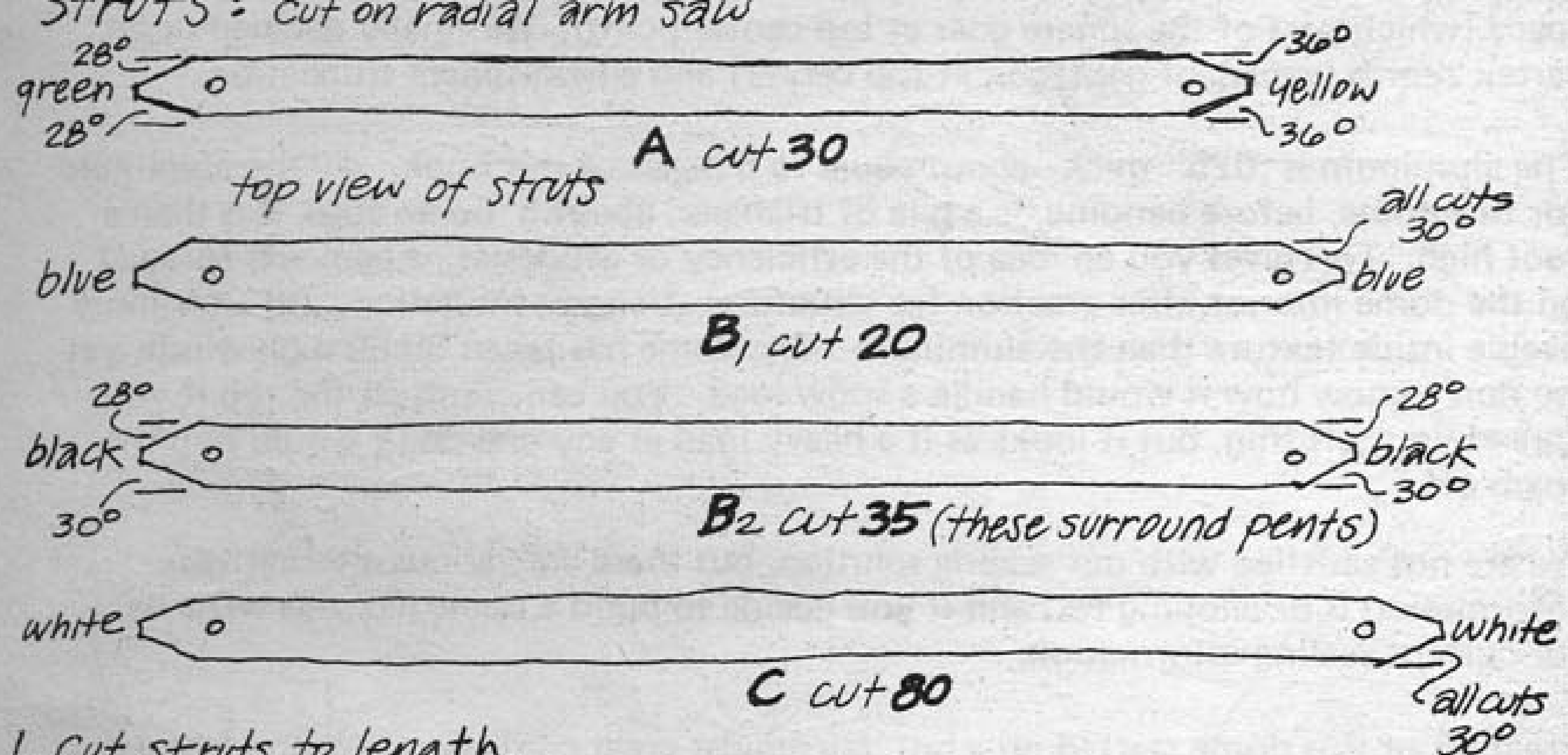

All C struts Make 15 code white

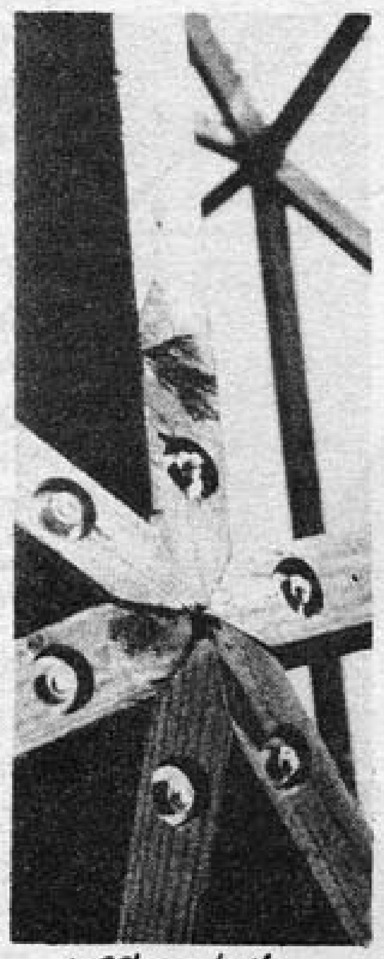



Make 40

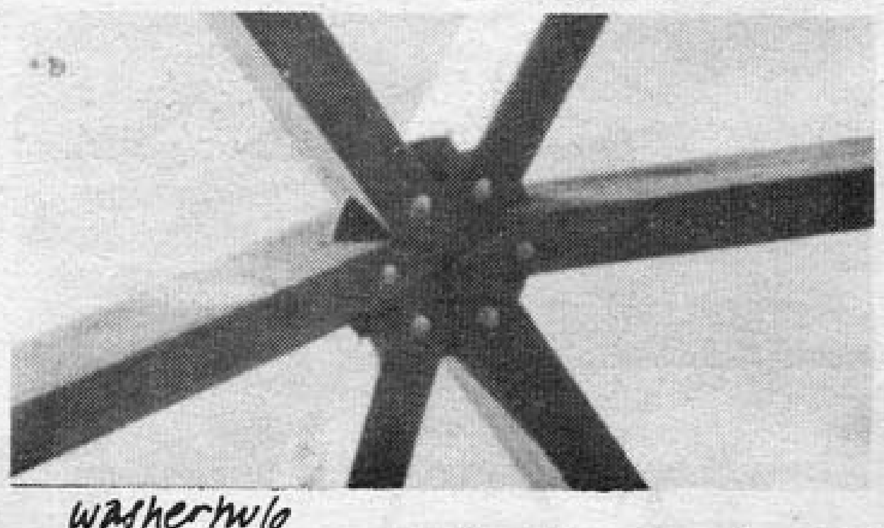
- use 3/8" zinc plated carriage bolts with bolt length the same as the actual depth of the strut. You'll need about 400 bolts.
- use 3/16" steel plate (this is width of 2 saw blades.) Have hubs cut at metal shop if you can't find 6" washers.

Struts: cut on radial arm saw

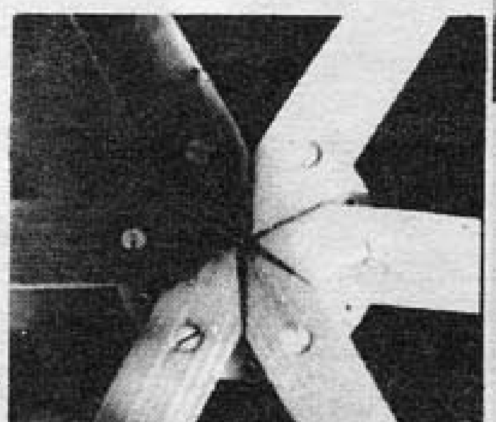


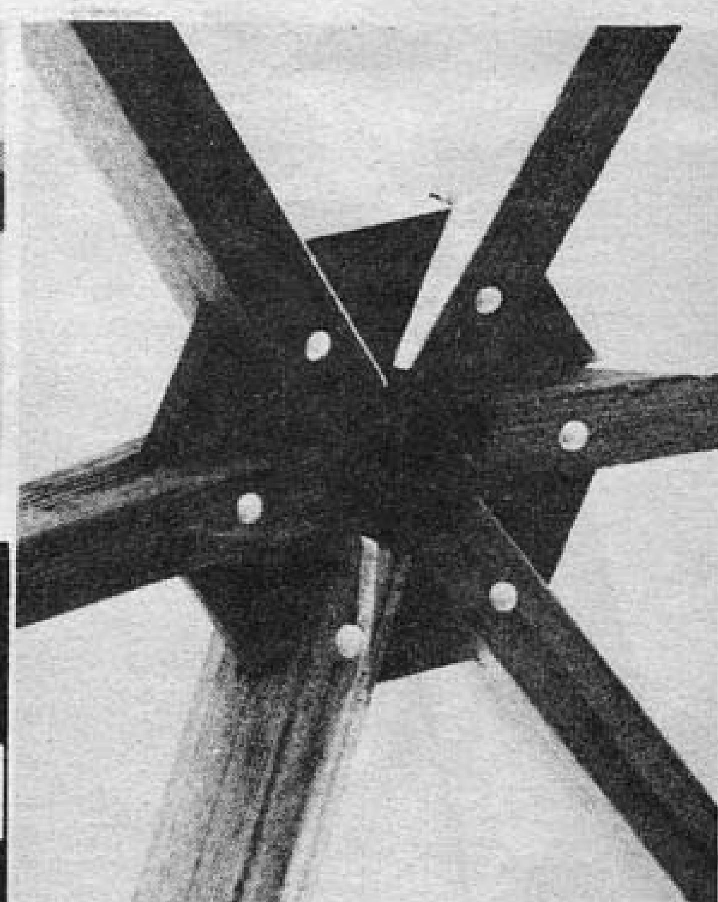
washer hub



washerhub



washer hub with lag screws by John Stolurow



plyhub

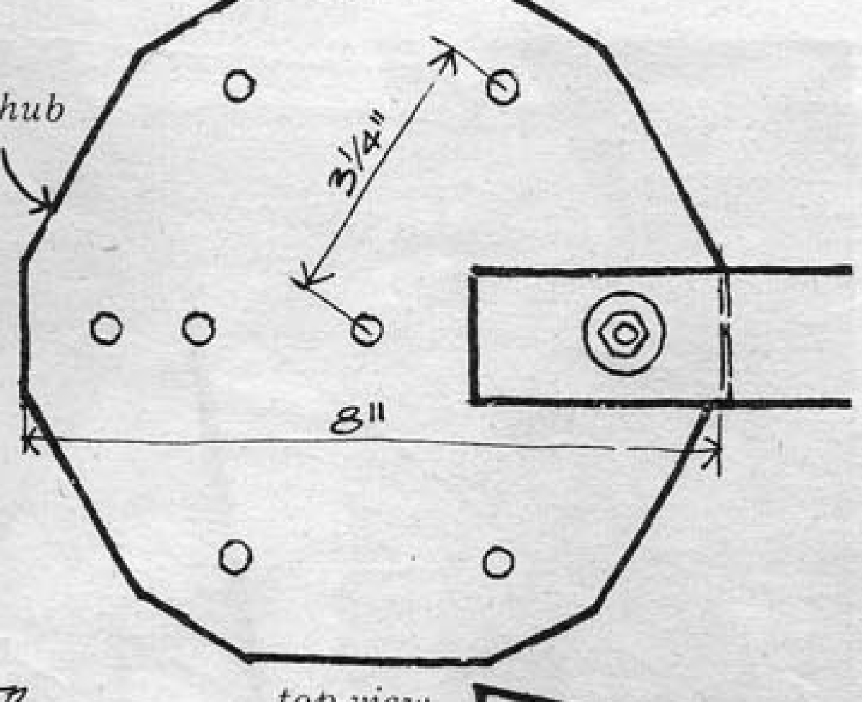
1. Cut struts to length. end angles similar to Pacific Dome
2. Cut mitering angles. We left 1/4" flat at ends of struts for a sure stop to get accurate angles.
3. Countersink for holes, then drill (3/8") wood bit is best.
4. Notch for hub; use 2 blade together, shim with cardboard.

## Plyhub

- easier to make
use a good grade of exterior plywood

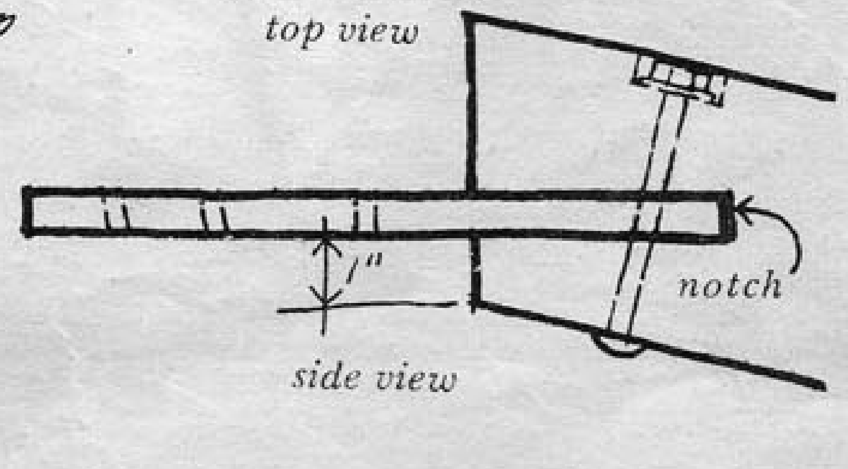
- the hubs can be cut quickly on a table saw, first cut the large angles (use the sliding guide), then flatten the sharp angles.

- make the notch with two cuts on the saw, or with a dado blade. If you make two cuts, finish the notch with a chisel.



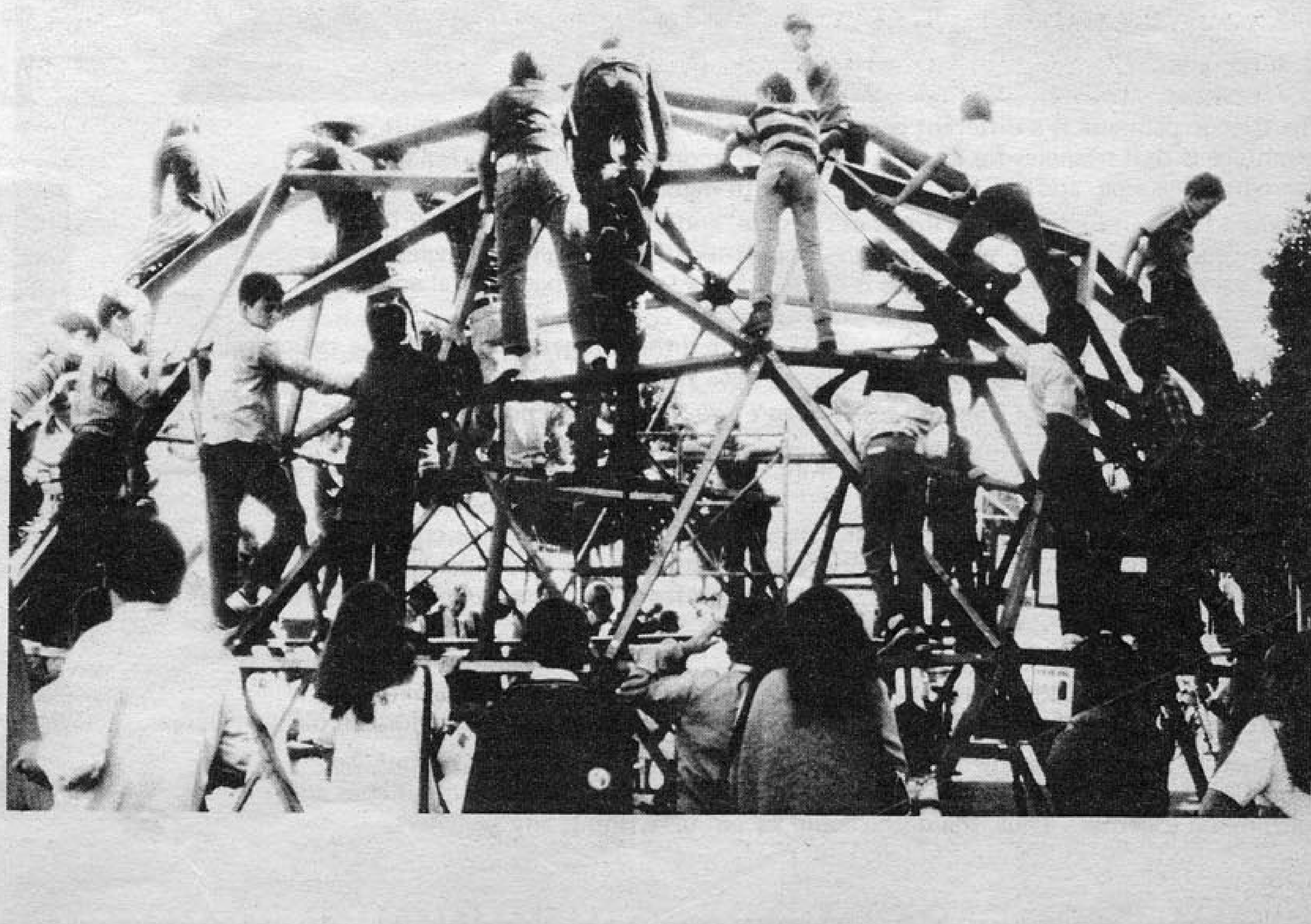

1/2" plyhub

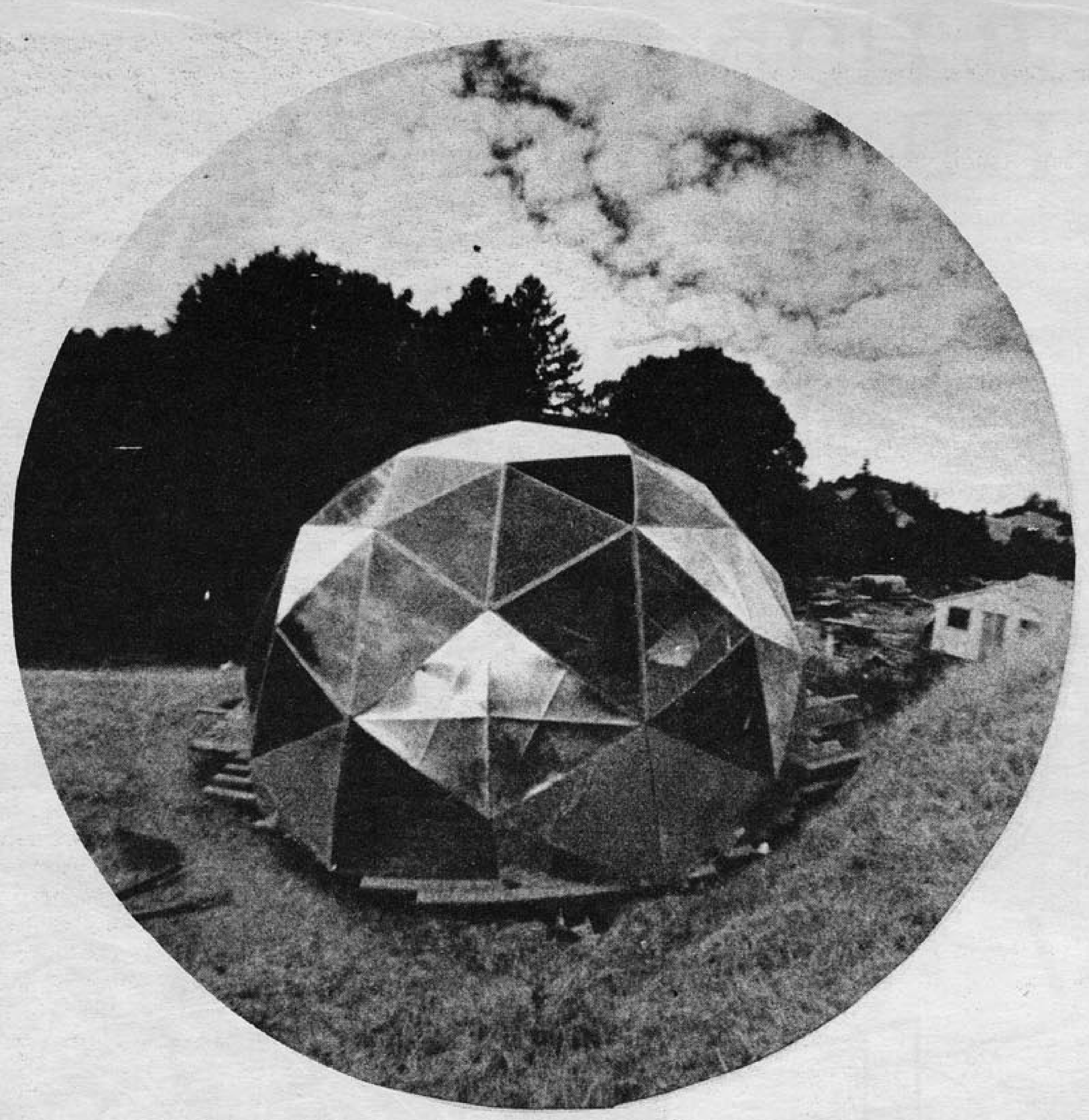
top view




notch

side view

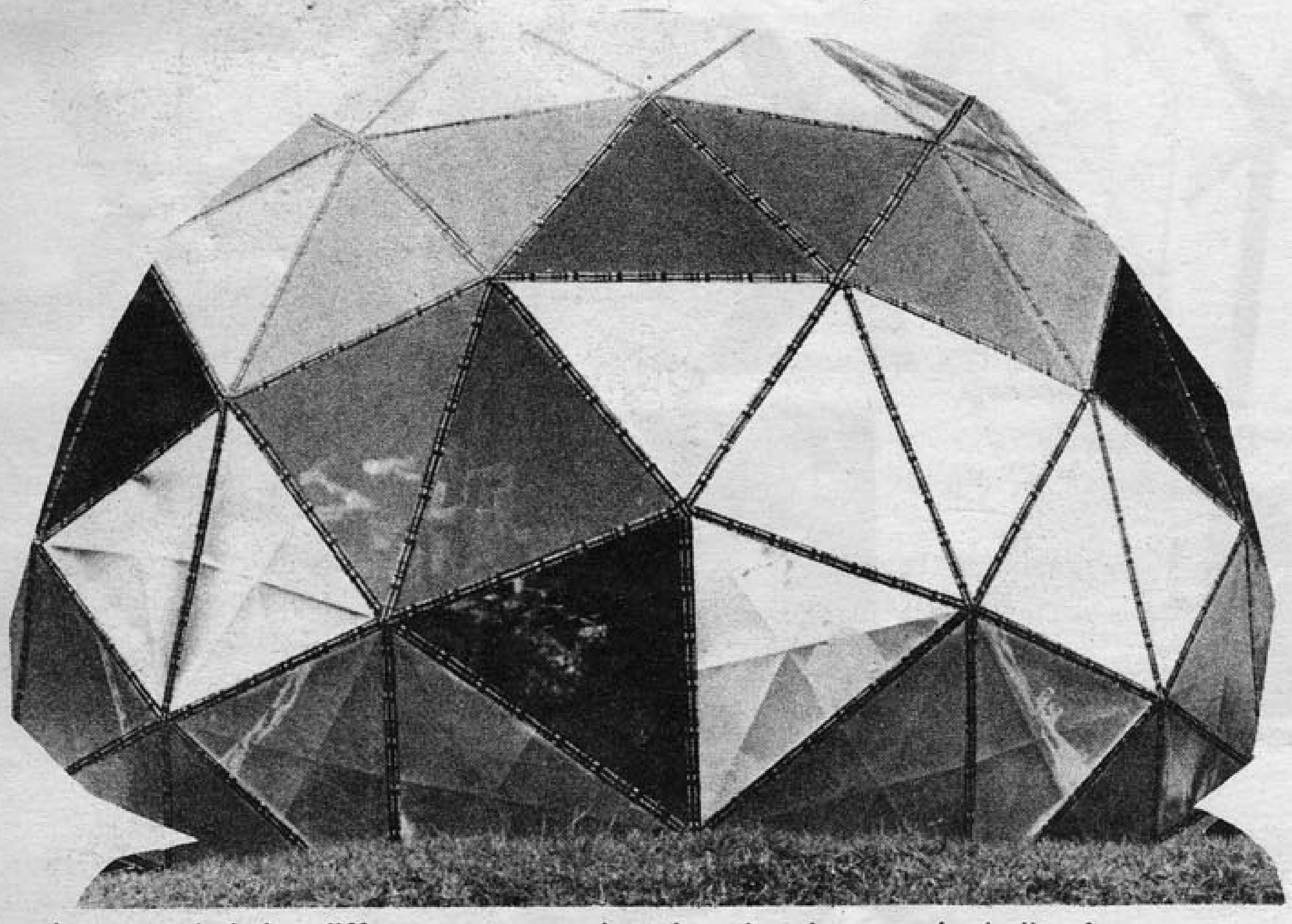




# ALUMINUM TRIACON DOME

Wayne had built a camper for his truck out of shiny aluminum. Some scraps were laying around the shop for a while and I kept looking at them, digging the shiny surfaces. I kept thinking how spacy a shiny dome would look in a field, reflecting the surrounding trees and grasses. Talking to Douglas Deeds on the phone one night, I found out that he had a roll of aluminum left over from a project that he'd sell for $200. So we bought it, and it turned out to be enough for two domes.

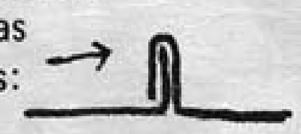
The roll weighed about 600 pounds, was 4' high, about 3' in diameter. When we picked it up in the truck, it was hard to believe that it contained enough skin for **two complete domes.**



The triacon geodesic is a different geometry than the other domes we've built. An advantage is that triangles for the 24' diameter triacon are smaller than for the alternate 24' dome, and can be cut from 4' width material.

I wanted to try as lightweight a dome as possible, and in construction detail I was influenced by our radome, which is made of bolt-together fiberglass triangles. Steve Baer's garnet crystal zome in Placitas is made this way, with flanged metal edges of chopped-out car tops.

I planned a single flange on each triangle, then bolted them together to make the structure. I went to Shanrock Sheet Metal in San Jose to have five test panels made; the foreman said, *"You're going to use standing seams aren't you?"* I didn't know what he was talking about, and he explained that standing seams are used on sheet metal roofs:



It was a good idea as a means of locking things together, giving an extra edge of stiffness along strut lines. We put the standing seams *inside* (they're outside on tin roofs). Another thing I learned at the sheet metal shop that day was cross-braking: making slight creases in the metal, giving a slight outward curve in the panel, which adds strength. I decided to cross-brake each triangle from vertex to opposite mid-strut; it was an aesthetic decision, it breaks the dome into many small triangles—closer to a sphere.

Flanging and cross-braking is done on a sheet metal brake, it's like a giant hinge. Shanrock made five test panels for us. We locked them together, and they looked ok..

I planned to use pop rivets or self starting sheet metal screws for fasteners, but in a vocational sheet metal shop discovered a tool called a *clip punch* which punches and holds metal together. Thus, the dome could be put up without any fasteners.

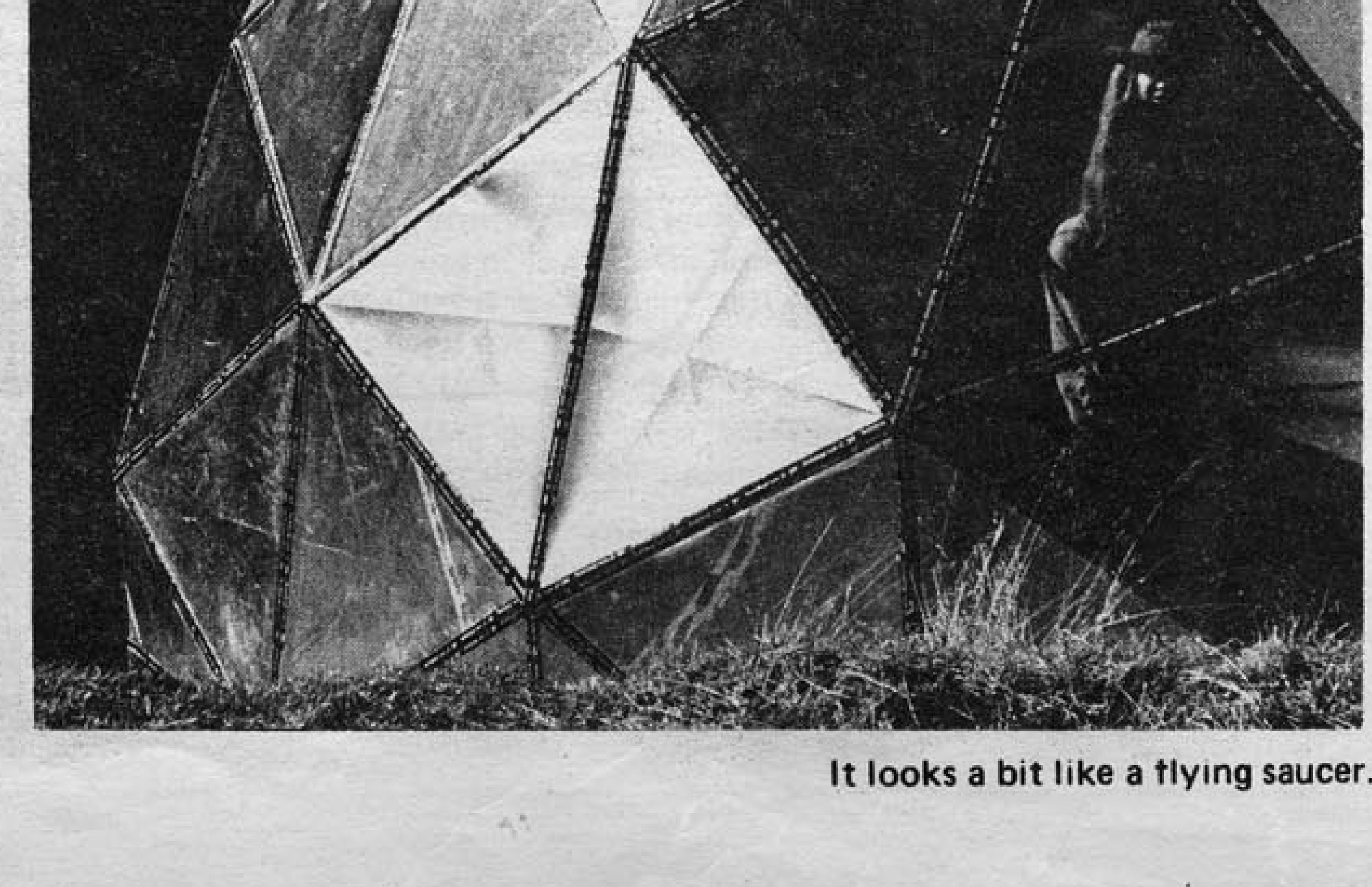
Kip made a dowel model of the triacon, and we hung it in the shop, trying to decide how to cut off the sphere to make the dome. This involves different orientations in space (which part of the sphere goes at top center point). We finally decided upon vertex zenith (center of pentagon at top center) and a hemisphere truncation.

The aluminum is .025" thick—about equal to 5 pages of this book. *All* the aluminum for this dome, before bending, is a pile of triangles, about 5' on an edge, less than a foot high. This gives you an idea of the efficiency of geodesics. Foam was sprayed on the dome interior after erection for structural strength, insulation, and a far more livable inside texture than the aluminum. The dome has taken 50-60 mph winds, yet we don't know how it would handle a snow load. You can climb on the top if you spread yourself thin, but it looks as if a heavy load at any one point would pop the foam off.

We are not satisfied with our sealing solution, but there are various alternatives. Information is developing fast and if you decide to build a dome like this write us for current sealing information.

Erection of this dome started on a hot day amidst great confusion. We thought we knew so much about domes that we didn't have to color code triangles, and the result was instant chaos. Finally we put one person in charge, designating what goes where; when we got going we had about 20 people, a lot of noise and excitement. The dome was floppy and we needed many people to hold it up, especially with the lower courses.

Watching the new geometry piece itself together was exciting, suspenseful (we weren't sure it would work), like seeing a new flower grow. We finished it in the moonlight.



It looks a bit like a flying saucer.

**VITAL STATISTICS**

Geometry: 4-frequency geodesic, ½-sphere(hemisphere) icosa-triacon breakdown, vertex zenith

Diameter: 24'

Weight(not including floor): about 600 lbs(300 alum, 200 foam, 50 wood, 50 misc)

Volume: 3620 cu ft

Floor Area: about 450 sq ft

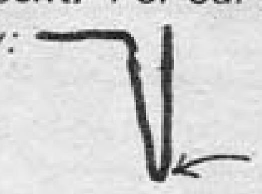
Note: volume is a far better measure of space in a dome, as you're not confined to the floor area.

Date built: October, 1970, in California hills

**DOME INGREDIENTS**

- –300 lbs (will vary with amount of windows) roll of .025" No. 3003 aluminum
- –about 250 lin ft wood or aluminum angle for window frames
- –150 galvanized ¼" X 2" hex-head bolts with washers and nuts for fastening window frames to aluminum flanges
- –vinyl washers where galvanized bolts touch aluminum, to prevent possible electrolysis. Cut them out of vinyl with scissors.
- –3/16" diam ¼" work thickness aluminum pop rivets if clip punch doesn't seem strong enough
- –about 200 lbs of Pittsburgh Plate Glass No. 65058 spray-on polyurethane foam
- –2 gallons PPG Polyclutch Acid Solution and Wash Primer as primer on aluminum before foaming
- –few boxes of Nichols 1¾" aluminum nails with rubber washers for nailing base ½-triangles to wood frames
- –misc. materials for vent, door, etc.
- –floor materials not included

*No. 3003 aluminum refers to the alloy. You can get the aluminum data books listed in the bibliography free. Very briefly: the number (3003, 3004, 5005, 5052 etc) refers to the alloy and tells you the amount of chrome, magnesium, other metals in the alloy, and indicates differences such as corrosion resistance, grain texture and finish. The alloy number is followed by a designation like this: H12 or H18; this indicates the hardness or temper. This is very important, as, if the aluminum is too hard it will crack when bent. For our purposes, the metal must be malleable enough to bend thusly:*




*This is not a problem with galvanized steel or cartops. However, if you use aluminum check with the distributor, then try some tests on a sheet metal brake and see if the metal cracks or has fissures.*

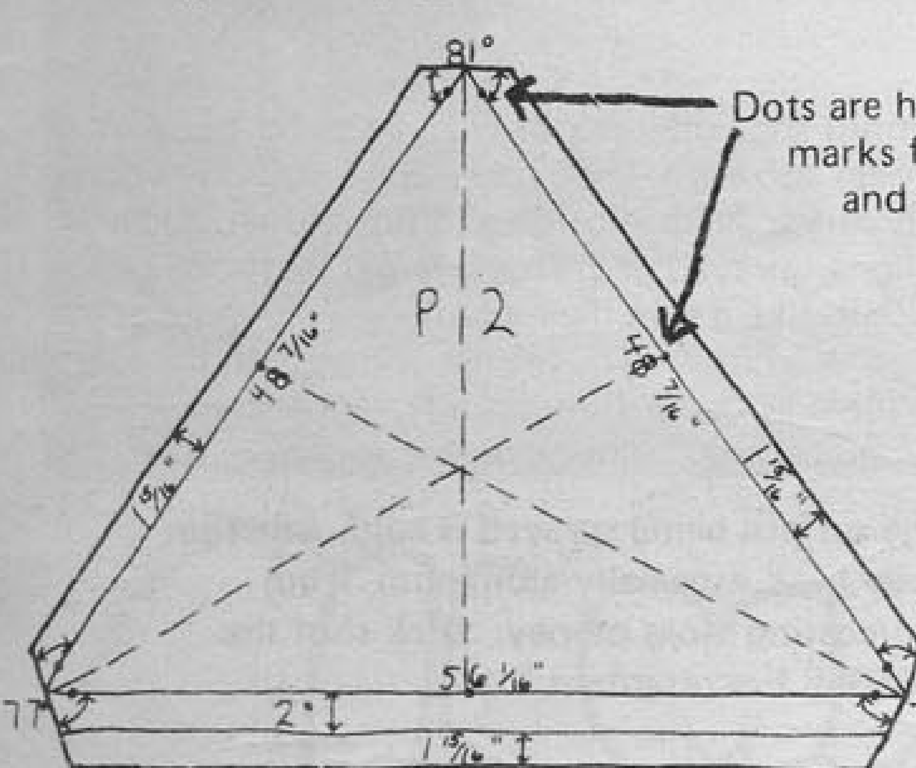
**BUILDER'S INSTRUCTIONS**

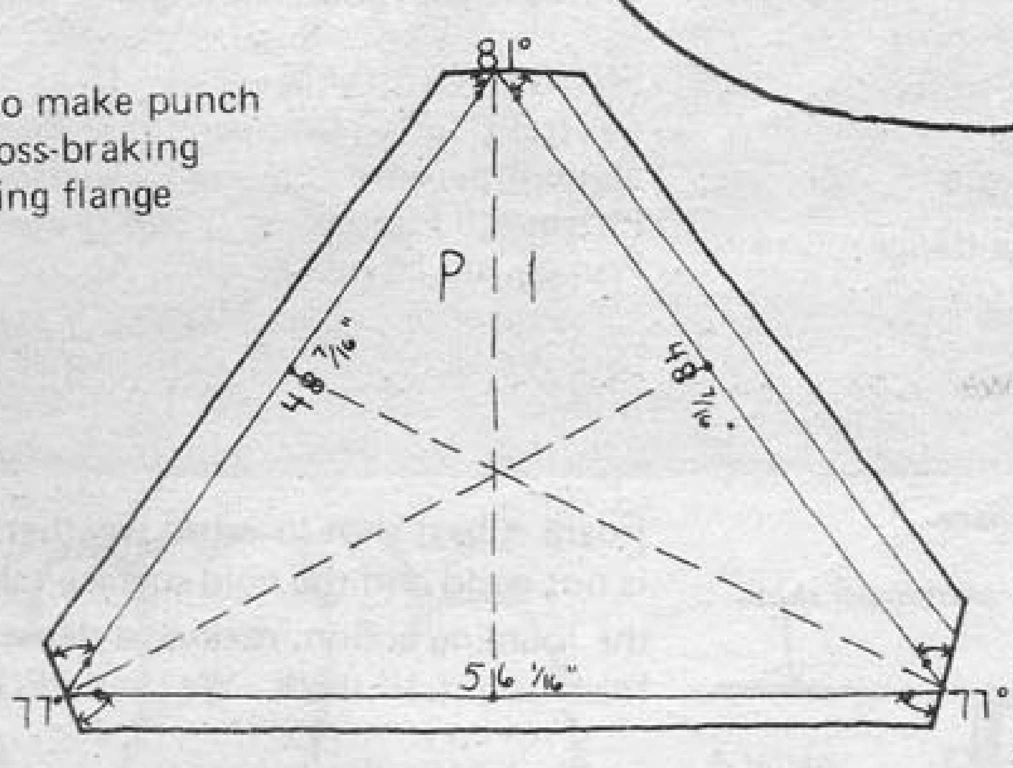
Be sure to make both a dowel model and a membrane model of this dome before building one. Color the cardboard model according to triangles: P1, P2, QR, QL and you'll see the pattern.

We made our seams 2" deep. They should have been about 1" deep to have the clip punch work properly (more on this later). If you use pop rivets or sheet metal screws for fastening, the 2" is OK. If you use the clip punch, we'd recommend 1" seams and *you must adjust the templates accordingly.*

**Templates**

Templates are made of sheet metal, and used to mark the aluminum for cutting, cross-braking, and flanging.

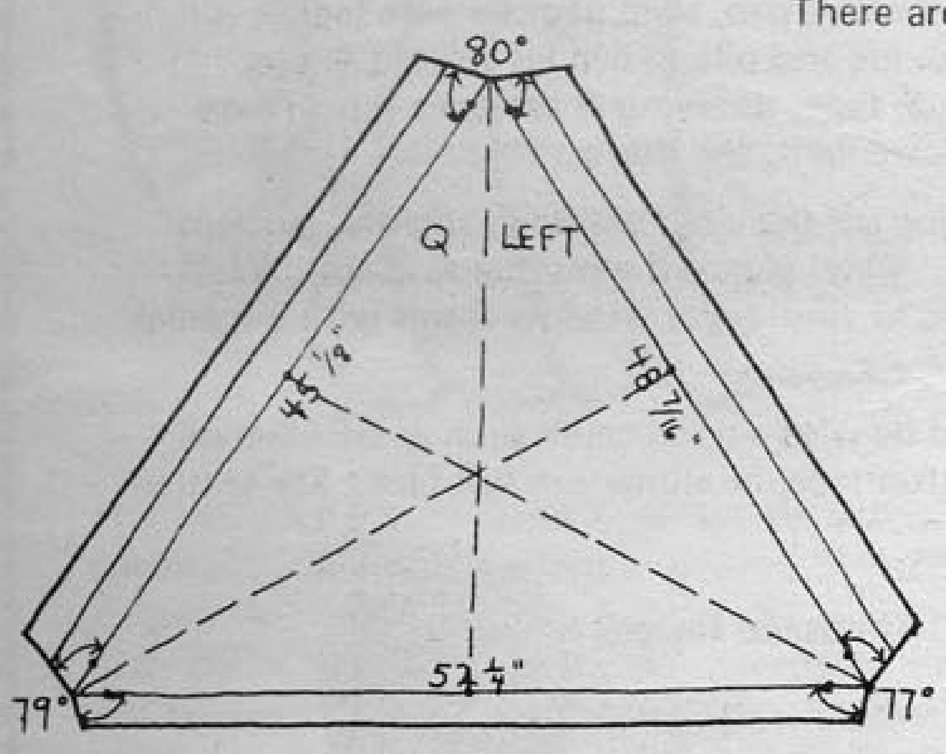


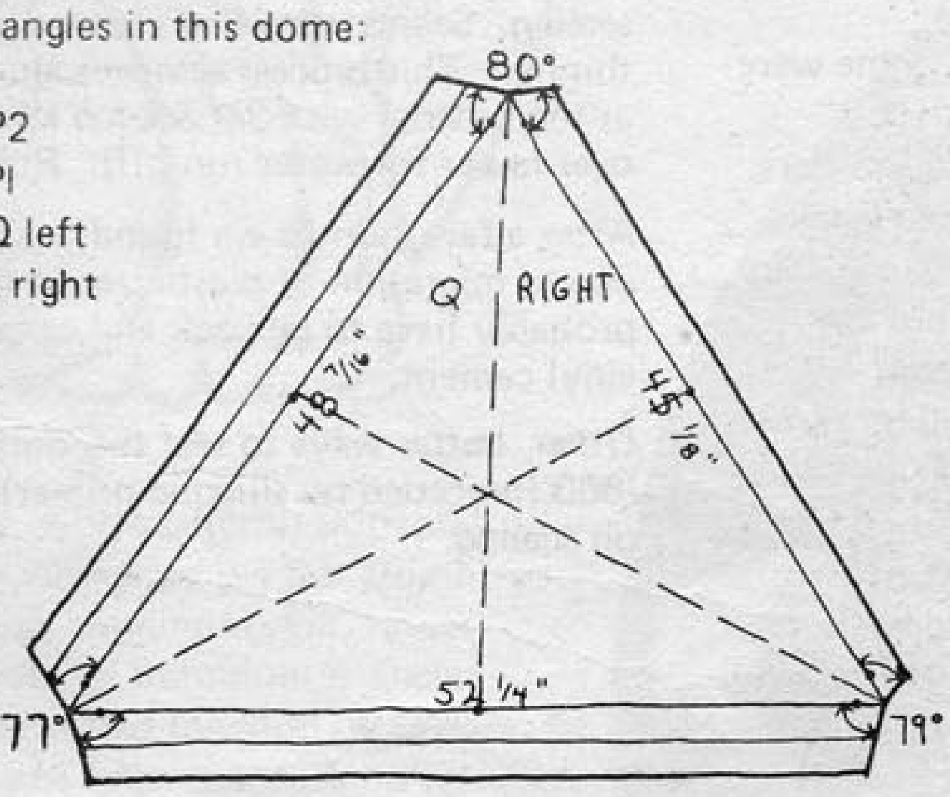




There are 120 triangles in this dome:

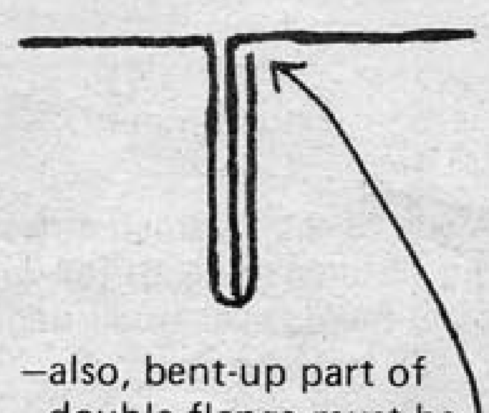
30 P2
30 PI
30 Q left
30 Q right



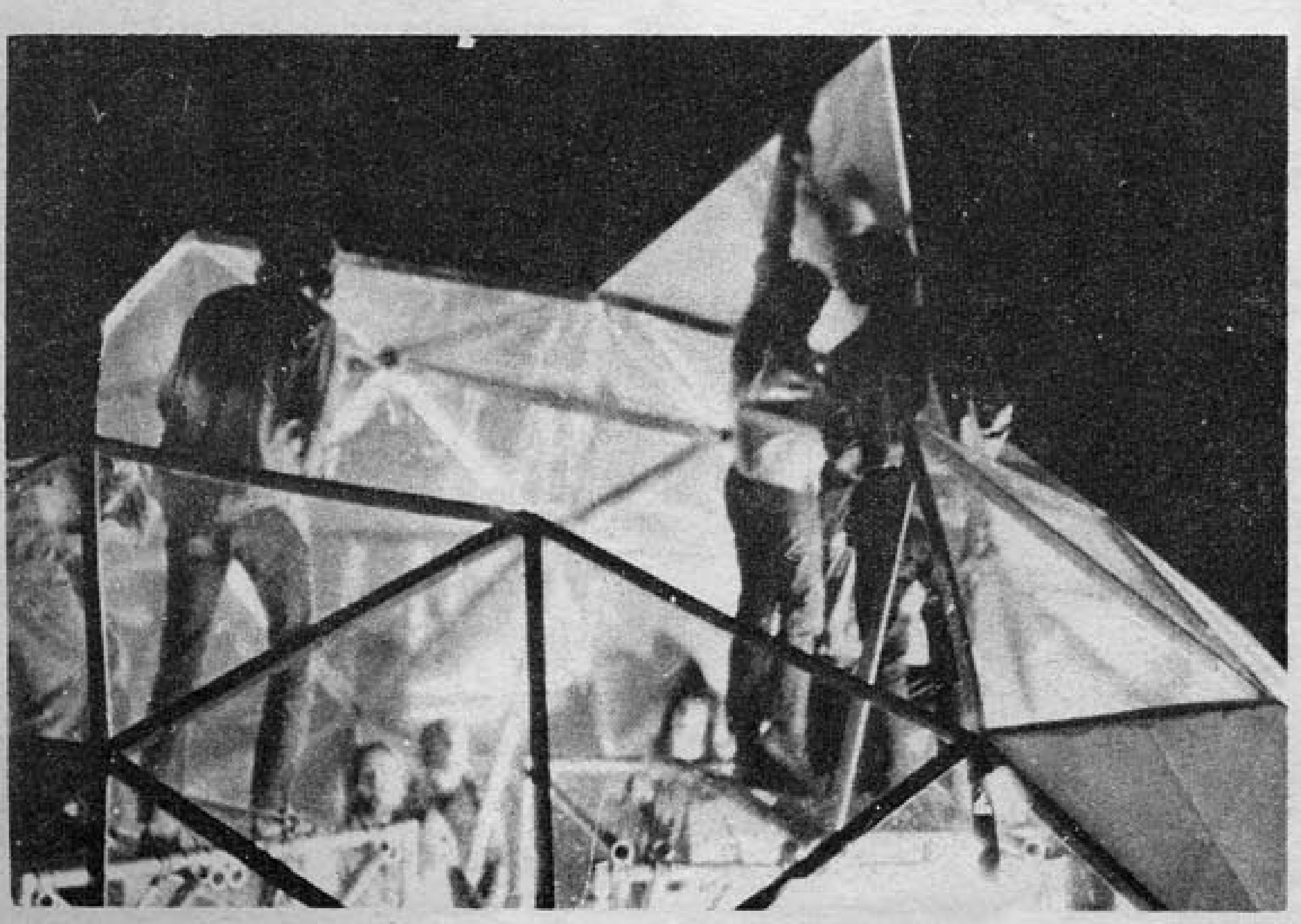


*Notes on template sketches:*
*–punch or drill 1/16" holes to mark for cross-brake. Holes are used to line up on the brake for cross-braking.*
*–these templates are worked out so that single flange always ends up with double flange of adjacent triangle.*
*–note that single flange must be a little shorter than bottom of double so when it locks in, skin of both triangles will be even:*



–also, bent-up part of double flange must be a little shorter as here.
–Peter calculated angles of the templates so flanged corners would come together when dome is put up.
–dotted lines show cross-braking.



**Marking and Cutting Aluminum**

Roll out aluminum on a smooth clean surface. Lay template on top. With awl or scribe scratch pattern on aluminum. With hammer and awl, punch through the template holes to make mark on aluminum for cross-brake and mid-seam.

Cut along scratched lines with heavy tin snips, stacking triangles as you go.

It will simplify matters during erection if you *color code* triangles as you go, keying colors to model. Work out a color for an edge of each triangle, dab or spray paint on.

### Sheet Metal Brake

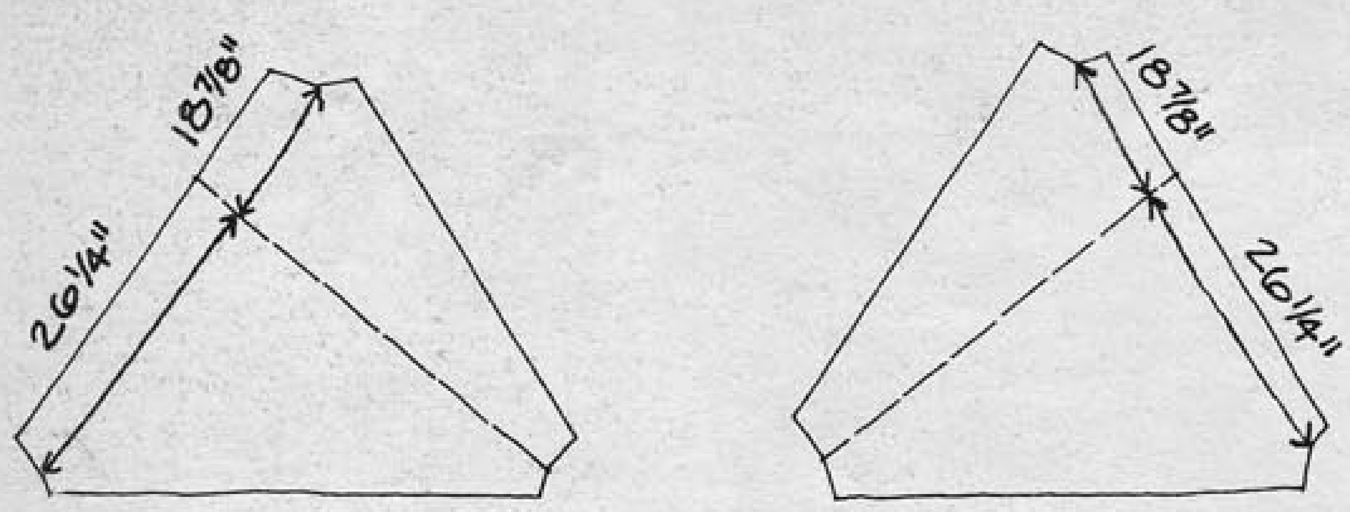
You might be able to make a brake, but it will be far easier to borrow one somewhere. We enrolled in a vocational school sheet metal class and used their 8′manual brake. Or you can get a price from a local sheet metal shop for having the work done.

Four of us worked well as a team; one at either end working the brake levers, two in the middle lining up marks on the triangles. The two in the middle feed and remove triangles. Once you get into it a rhythm develops and the work moves fast.

**Cross-braking** is done first. The cross-brakes on the triacon were shallower than those on the sun dome. I like the deeper cross-brakes better. Make the three cross-brake seams by bending the metal about 20°.

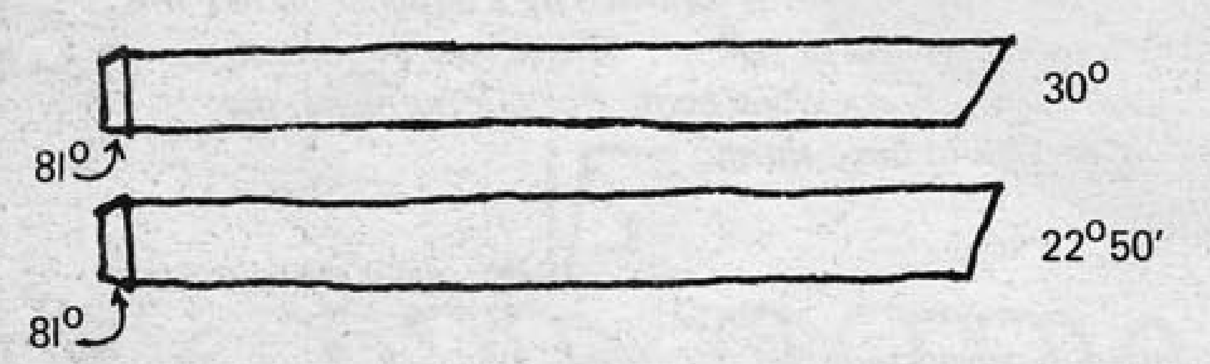
**Braking seams.** Keep drawings of triangles in sight so you brake in the right direction. Get someone with sheet metal experience to show you the best way to make the double seams.

**Base triangles.** You will cut five of the QR's, five of the QL's for base triangles. Cut like this:



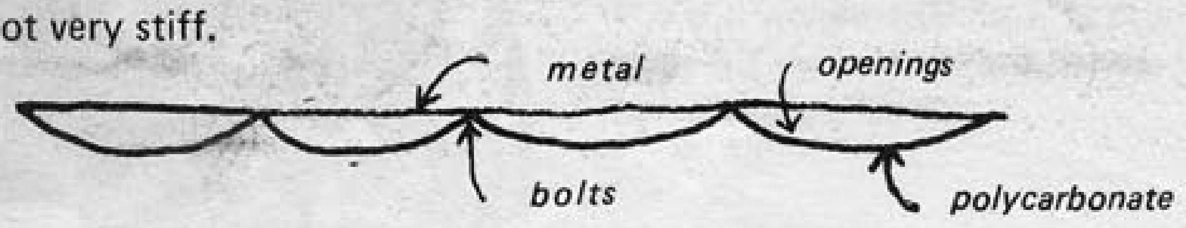

### Wood frames for base triangles

We put wood pieces at the base of the half-triangles, nailed in with aluminum nails with rubber washers. These pieces—10 each—are cut like this:

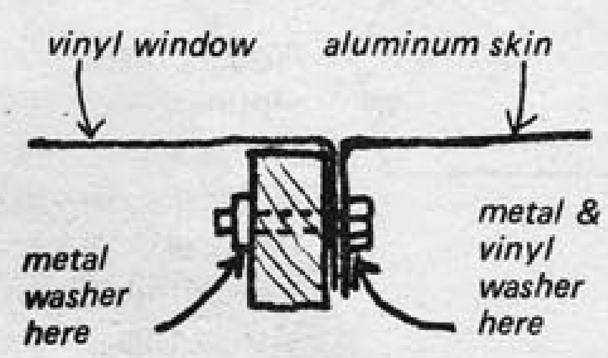



### Windows

We made sun dome type wood frames. You could also use aluminum angle frames with vinyl glued on. We've also considered making windows by bending polycarbonate sheet into single flanges and attaching to the aluminum with bolts. You're supposed to heat polycarbonate before forming, but we've made some 90° bends of the material on a sheet metal brake that looked OK. You'd have to check carefully to make sure cracks and fissure don't develop along the bend line. Another problem might be that the flange would not be stiff enough and you'd have slight openings in between fasteners as the polycarbonate is not very stiff.



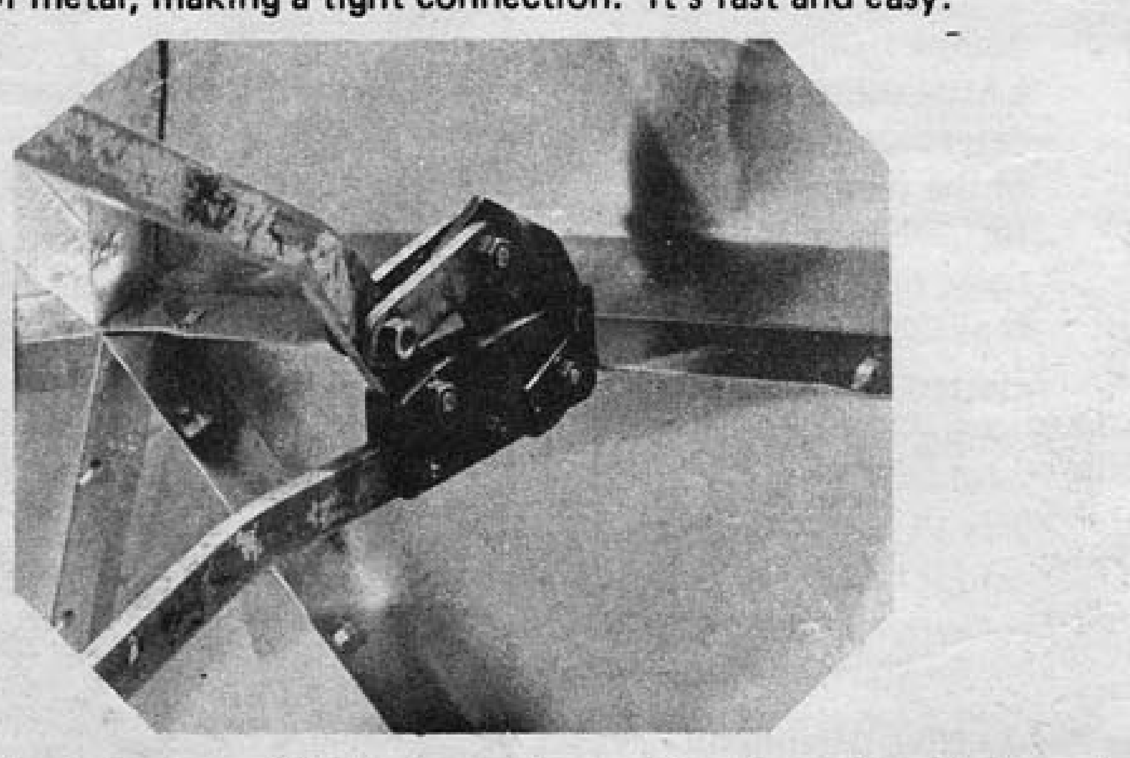

See Windows section on polycarbonate.



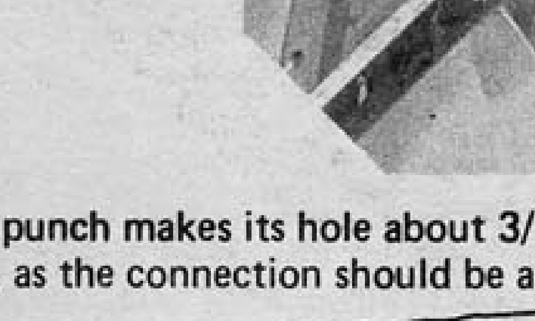

Windows in our dome were attached with ¼″ X 2″ hex-headed bolts, washers, and nuts. We used small pieces of vinyl against the aluminum to avoid any possible electrolysis with steel touching aluminum.

### Fastening

Two remarkable things about this dome: first that it is made of such a small amount of thin material; second, that it was put together without any fasteners(except for windows). To fasten, we used a *clip punch*, which punches through and bends over small flaps of the adjoining pieces of metal, making a tight connection. It's fast and easy.



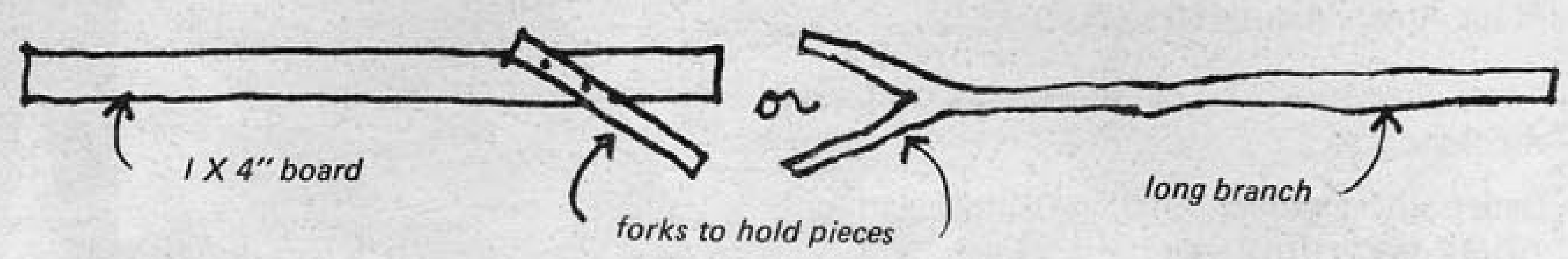
The clip punch makes its hole about 3/4″ in from the outside edge. This didn't work too well, as the connection should be as close to the skin as possible to stop flexing.




Since we had flexing here we went back after erection with a drill/90° attachment, drilled holes as close to skin *and vertexes* as possible and used aluminum pop rivets. This strengthened the dome considerably.

### PUTTING IT UP

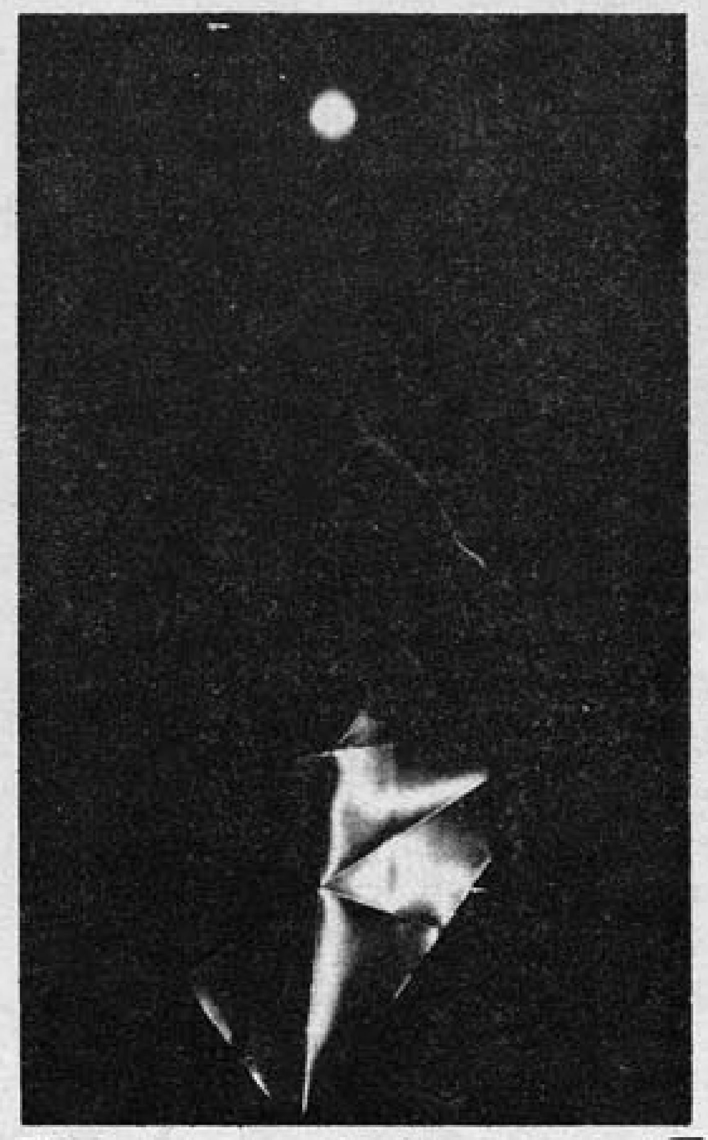
One person should direct what goes where, using the color-coded cardboard model. The model should be coded on the inside so that it corresponds with where you're looking at the dome from. You need a scaffold, and a large crew—15 is good—to hold things up for the first few courses. If you don't have that many people, you can prop with sticks.




Start at the bottom with half triangles with wood bases. Pound (gently) seams together with rubber mallet on outside, holding wood block inside.

Teams will form naturally, a rhythm beginning as the skin spins together.

We started in the bright morning sunlight and finished by moonlight. Everyone that came to look stayed to help.



**This is the moon shining on a triangle.**

**When it was finished we had** dinner in the dome, then turned on a floodlight and looked at the window patterns from outside.

### SHOOTING FOAM

Central Coating Company (see Foam section) shot the interior with foam for us. As aluminum is not too good a surface for foam adhesion, Dick sprayed it with a two-part Pittsburgh Plate Glass (PPG) primer: Polyclutch Acid solution and Polyclutch Wash Primer, mixed one to one. About 1½ gallons, sprayed on. This is *lethal* stuff. Whoever sprays it should have an outside source of air, like a skin diving tank or a compressor (Bill Woods uses a vacuum cleaner and a garden hose). The primer comes with Polyclutch thinner for cleaning up. The primer gets the oil off the aluminum for good foam adhesion, and you're supposed to wait 24 hours after priming before spraying foam.

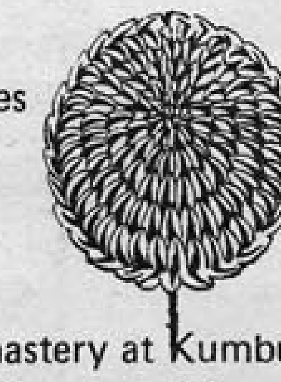
Foam is best shot in warm weather. If the surface being sprayed is cold, adhesion is not good and the cold surface takes away heat, especially aluminum, from the foaming action, making a denser foam/costing more money. Dick shot the foam about 1″ thick. We used PPG No. 65058 fire retardant foam.

**Sealing:** We first tried blue vinyl electrician's tape but it didn't work. Where tape sticks to tape, as at vertexes, it peeled off, as it is coated with a release agent. Pipe wrap tape however, is made to stick to itself, and this is what we used next to attempt sealing. Seams were first cleaned with an abrasive pad, then painted with laquer thinner. This process removes aluminum oxide and oils. Then we started taping at the bottom with *3M Scotch Wrap* 2″ wide tape, shingling at vertexes (upper tape over lower for water run-off). Rub tape down well, and don't stretch it.

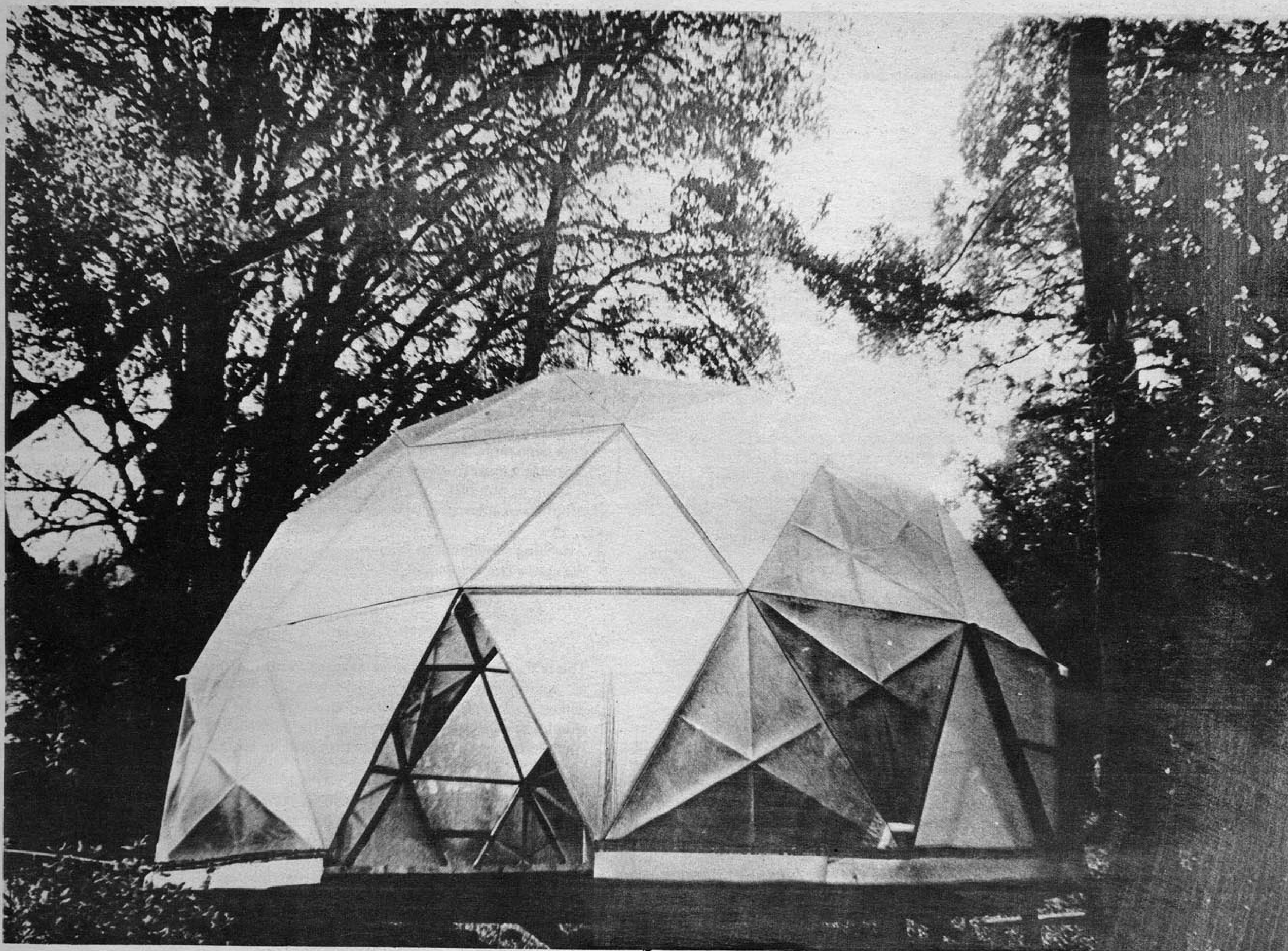
After a few months we found the tape lifting off the vinyl windows slightly, perhaps due to migration of plasticizer in the vinyl. Vinyl gives off a residue as it ages. We'll probably have to go back and cement strips of vinyl on at window seams with a special vinyl cement.

Other, better ways to seal this dome would be with a good caulk such as GE silicone 1600 (preceded by silicone primer) or elastron tape, or aluminum foil tape. See section on sealing.

Thousand Images



In the great monastery at Kumbum, in Sifan, near the frontier of Tibet and China, is or was one of the most remarkable of all magical phenomena. It was enclosed in a square, formed of brick walls, near the main temple of the aforesaid monastery, and over it had been erected, at the expense of one of the Chinese emperors, a dome of silver. On each of the leaves of the tree were imprinted well-formed Tibetan characters, all green, some darker, some lighter, than the leaf itself. The missionaries were unable to discover the least sign of deception. The bark was also covered with characters, and when it was removed further characters were seen below.



# Aluminum Sandwich Dome

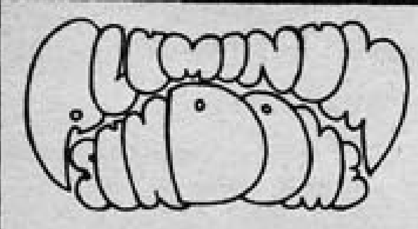
Our idea here was to make a lightweight portable dome, with a smooth skin, and hopefully, no waterproofing problems. Construction is similar to Big Sur Dome except that frames are very lightweight, and covered with aluminum skin, rather than plywood. We bent over $90^o$ flanges on the edges of the aluminum triangles, fitting them over the wooden frames. Aluminum was attached to wood by pneumatic staples on the sides; this gave us a smooth surface at seams since there are no fasteners (such as nails) on the outside. We sandwiched a closed-cell neoprene tape in between panels to seal seams.

This is structurally much stronger than the aluminum triacon dome although the process of ripping, mitering, putting frames together, then stapling aluminum on is time-consuming.

This is a three frequency *alternate* geodesic, the same geometry and size as the Pacific Dome. A disadvantage, as compared to the *triacon* geometry is that the large triangles have an altitude of about 51"; you can't get a full large triangle out of a 4' wide roll of aluminum, and must add small tips. If you used sheet metal, you could probably get 54" wide sheets.

The dome was put up on a 2 X 6 wood pentagon floor. The five points where the dome touches the floor were lined up with the five lines in to the center of the floor. White styrofoam was popped in after erection for insulation; from the inside you see no metal: only the white foam, and wood struts. The interior is soft, white, and bright.

It's an easily portable dome.



## VITAL STATISTICS

Geometry: 3-frequency geodesic, 5/8 sphere, icosa-alternate breakdown, vertex zenith
Diameter: 24′
Weight (not including floor): less than 600 lbs
Volume: about 4400 cu ft
Floor area: 452 sq ft
Date built: November, 1970, in California hills

## DOME INGREDIENTS

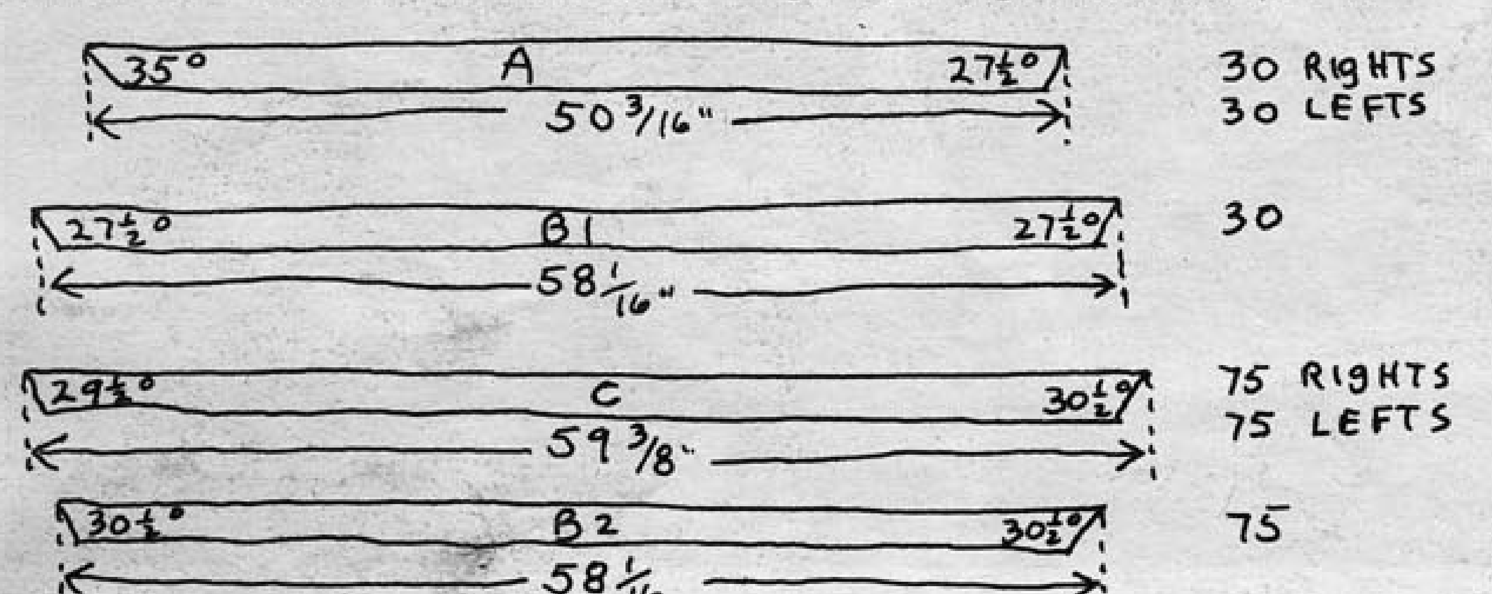
—about 350 lbs of aluminum (will vary with amount of windows)
—about 530 lin ft of 2 X 4's, ripped in half, then ripped to a 7° bevel. Use clear, knot-free lumber
—900 linear ft 3/16″ thick by 1″ wide closed-cell neoprene tape, adhesive on one side
—450 zinc plated ¼″ by 2″ hex-head bolts with washers
—9/16″ Duofast Monel staples
—two tubes silicone caulk for vertexes; sandpaper and primer for caulk
—35 sheets 1″ thick, 4′ X 8′ polystyrene insulation

## BUILDER'S INSTRUCTIONS

### Panel Frames

We made 2 X 4's, first cut in half on a table saw, then halves again ripped in half at a 7° bevel. We used cheap 2 X 4's—about $50 worth, and had to reject a lot of wood because of knots and warp. If we did it again, we'd get clear, knot-free lumber, especially since we're using so little of it. It's fascinating to compare the amount of lumber here to that used to frame an ordinary structure of the same size. Ask a local building contractor how much lumber it takes to frame a rectilinear structure covering 450 sq ft, and you'll see how domes can begin saving forests.

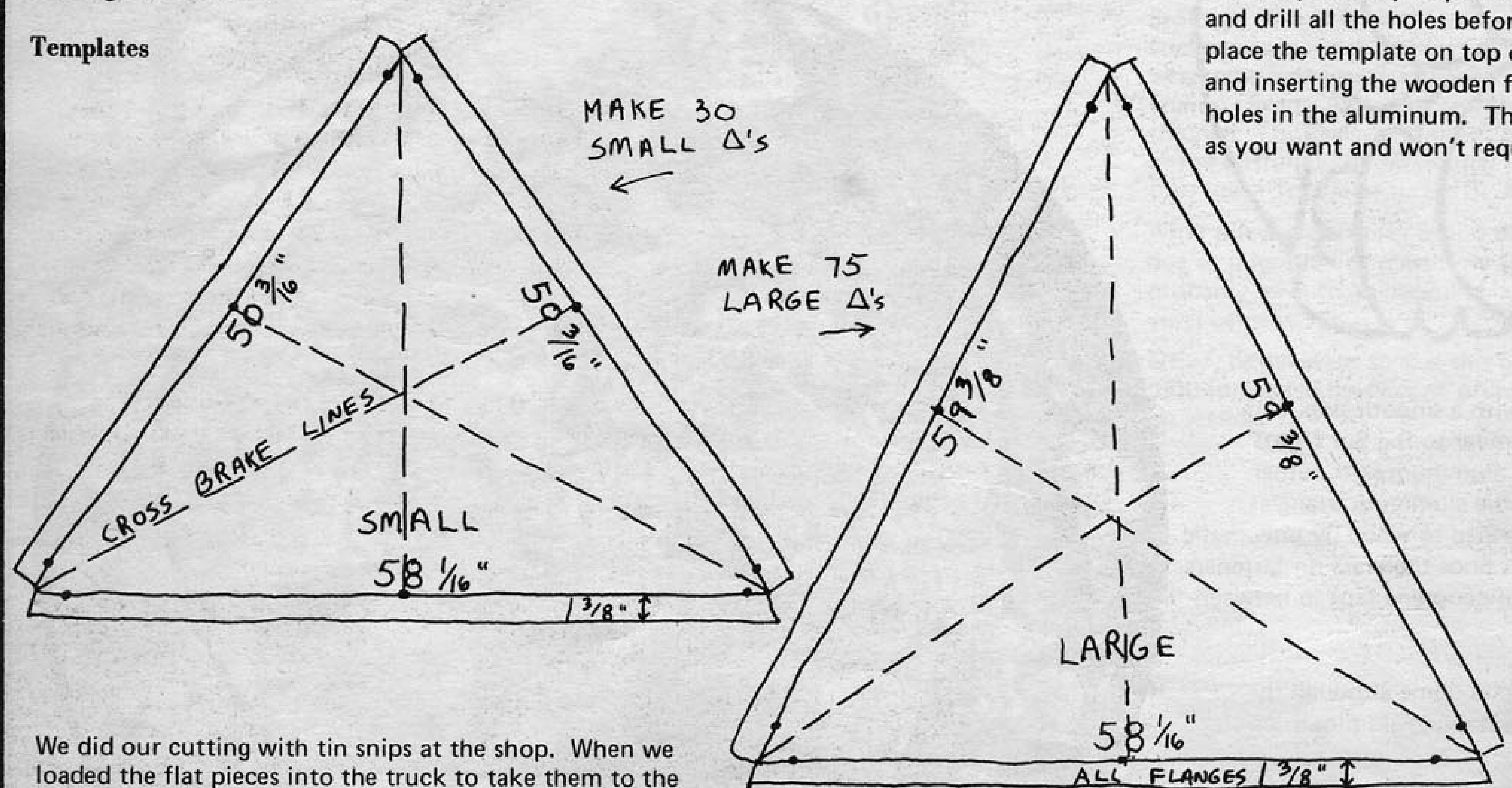
Techniques we used in making the panel frames are similar to those used in the Big Sur dome. After ripping, then cutting tip angles to length, we stapled the pieces into triangular frames with 9/16″ Monel staples and a Duofast gun at the tips, 2-3 staples each side. *This is not a good way to do it*, as staples do not hold the triangles together in tension; this weakness is not so important for triangles covered with aluminum, as the aluminum provides the strength. But if you use flexible window material such as vinyl, the frames need a stronger fastening method (see p. 14).




### Aluminum Skin

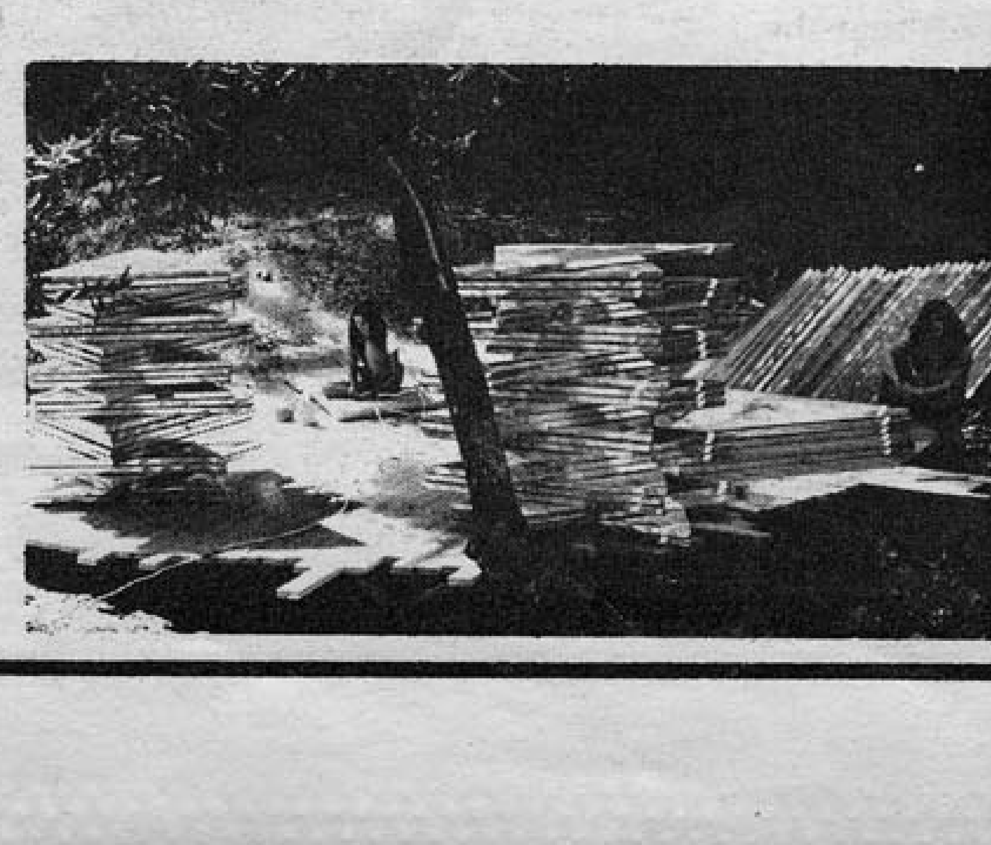
General procedure for cutting and braking the aluminum is the same as described in Aluminum Triacon dome. See **Template, Marking and cutting, Braking and cross-braking** on pp 27-28.

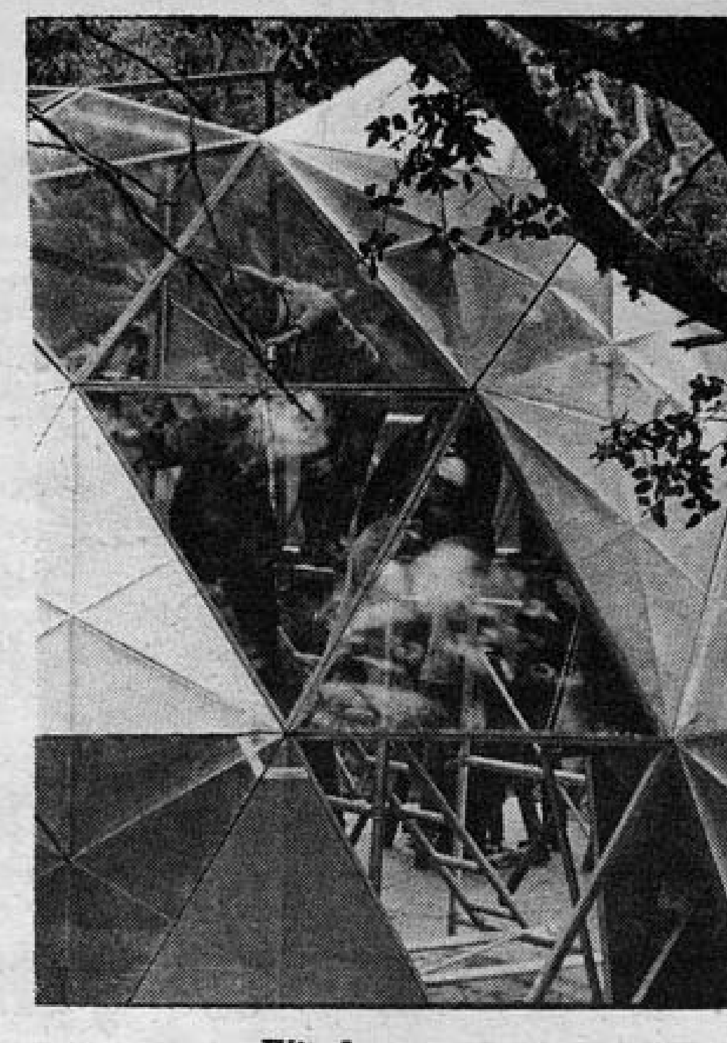
### Templates

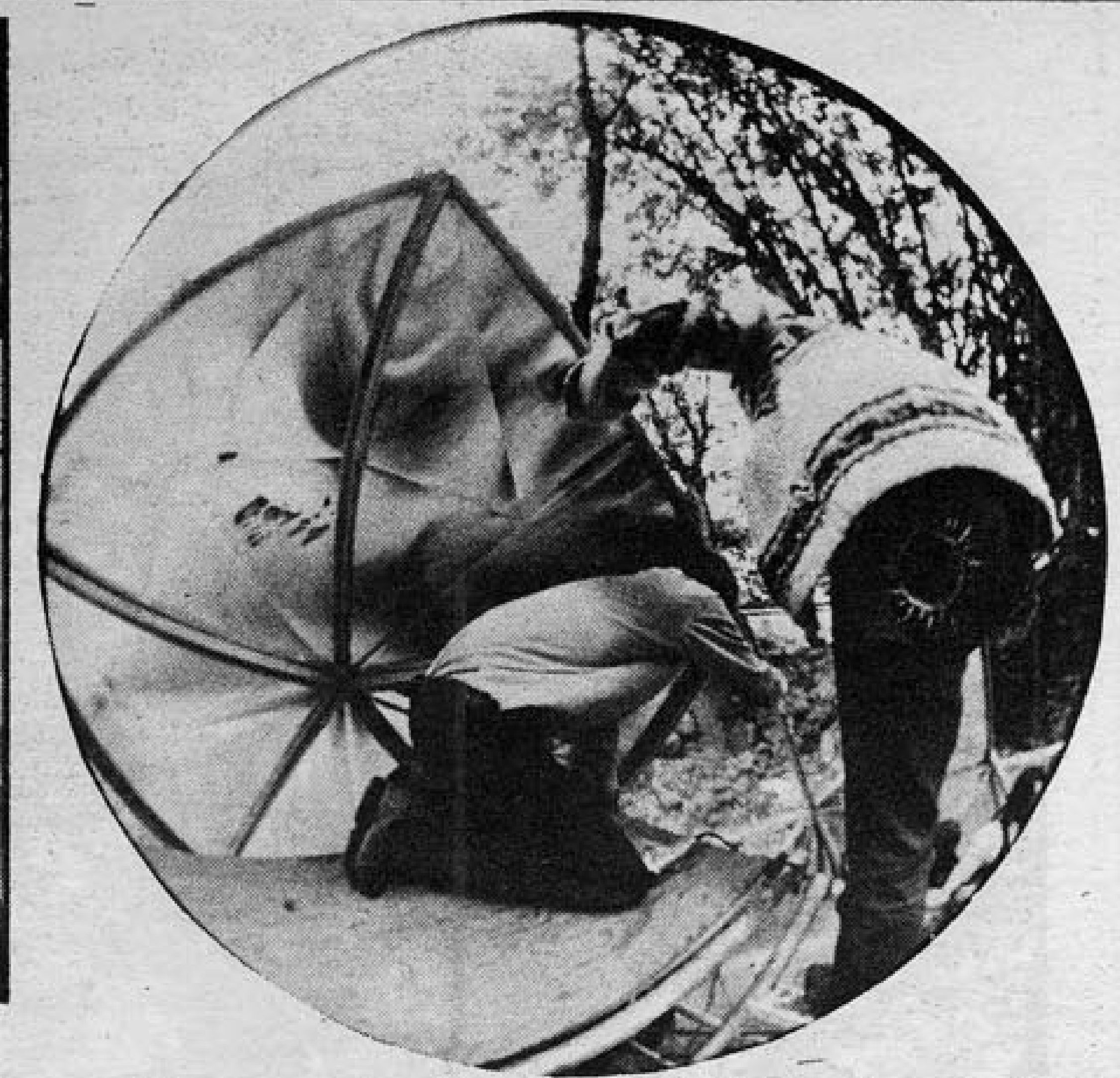



We did our cutting with tin snips at the shop. When we loaded the flat pieces into the truck to take them to the sheet metal shop, the pile of triangles—skin for the entire dome—was less than a foot high. Of course, after flanges are bent, they are much bulkier, but it was amazing to see the skin for 450 sq ft of floor space in such a small pile.

On the sheet metal brake we first did the cross-braking, then braked 90° single flanges around each edge. It took four of us about 4 hours on the brake to finish all triangles.





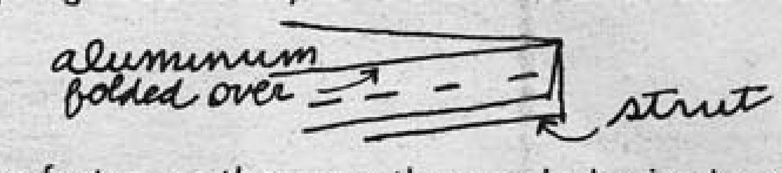


### Windows

We used vinyl, stapled on to wood frames as described on p. 17. By the time we did this dome I was sick of the ultra-violet resistant vinyl which gives you a distorted view of what's outside. With the light wood frame and white insulation this dome would have been more beautiful with optically clear windows. Clear window material can be plexiglas, Lexan (it might be possible to bend this over a wood frame—see Windows section) or non-distorting clear vinyl, such as sold by Scranton Laminates (see p. 86). All of these alternative window materials are more expensive than the vinyl we used.

### Attaching Aluminum to Frames

We used a Duofast Model BN-6424 staple gun with No. 4018-C Monel staples 9/16″ deep, 5/32″ wide, stapling about every 4″ on the inside of the frame.




This is the best place to fasten, as there are then no holes in the exterior skin. An air gun may not have been necessary here, as I believe there are hand staplers that will go through .025″ aluminum. Also, it may not even be necessary to attach aluminum to frames before erection: the bolts should hold everything together. We used the Monel staples rather than steel, to avoid any possible electrolysis.

### Attaching Tips to Large Triangles

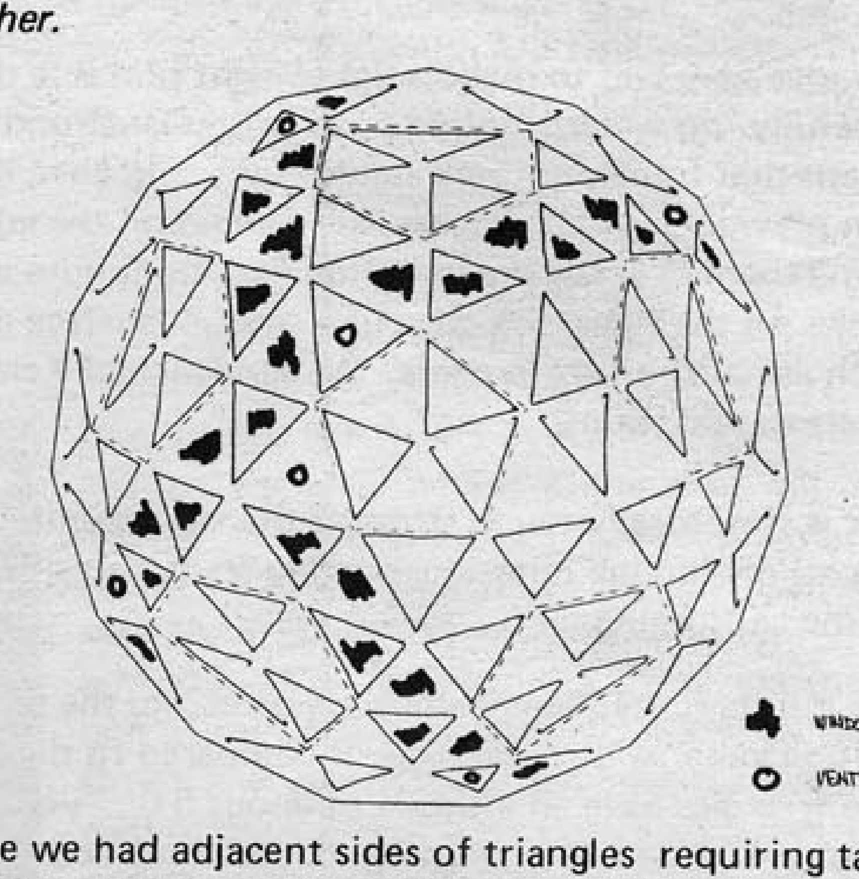
We didn't work out a good way to do this. We merely butted the two edges together and taped the seam, which isn't satisfactory for long range waterproofing. The tips are a good opportunity for colored glass—small colored hexagons form around hex vertexes.

**Drilling holes:** After stapling the aluminum triangles to the wooden frames and sticking on the neoprene gasket, we clamped adjacent triangles together and drilled the holes for assembly with an electric drill with a right angle attachment. We had three holes per edge—one centered and the other two as close to the corners as possible.

Having to carefully position and then drill the struts during erection was hard and time consuming; an accurate method of pre-drilling would make things a lot easier. The simplest way to pre-drill might be to locate the hole positions on the templates and drill all the holes before flanging. Using guides to hold the triangles in place, place the template on top of the stack and drill them all together. Then after flanging and inserting the wooden frames, drill through the wood from the outside using the holes in the aluminum. This will allow you to get the bolts as close to the corners as you want and won't require the right angle attachment.

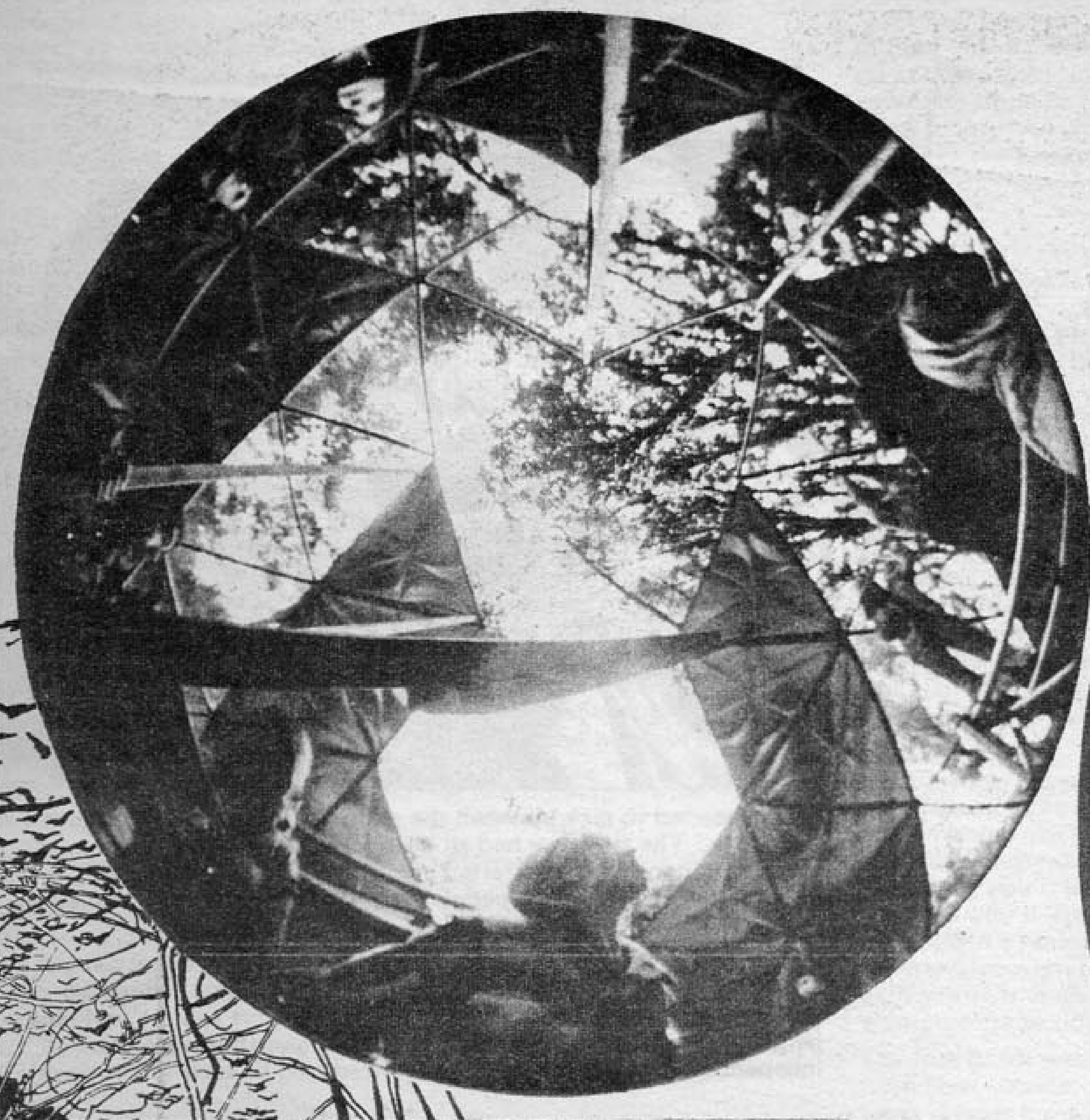
**Attaching foam tape:** The closed-cell neoprene foam tape that we used was 1″ wide, 3/16″ thick and came in 25 ft rolls with stickum on one side.

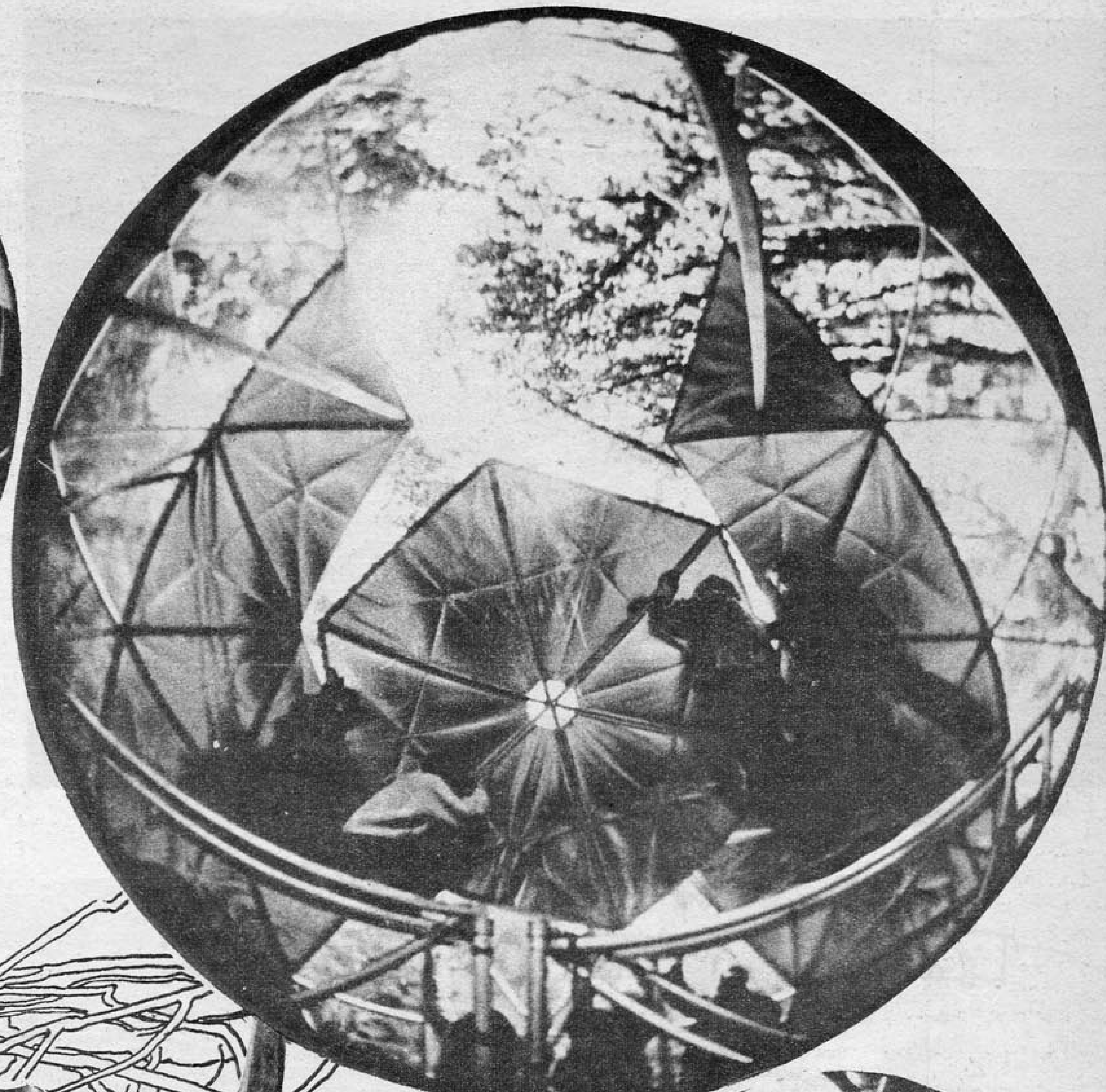
*We used this diagram to put tape on so that each seam only had one piece of tape when triangles were bolted together.*

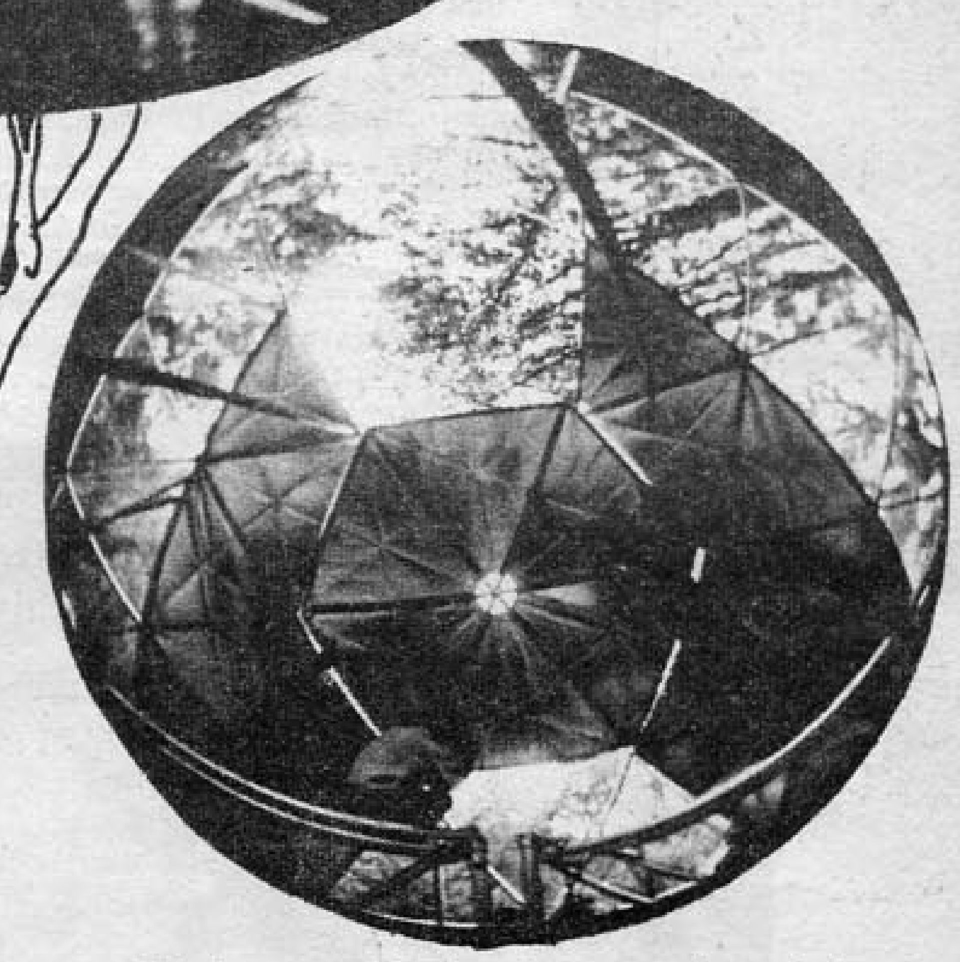



Where we had adjacent sides of triangles requiring tape, we ran the tape right around the corner, hoping that this extra neoprene would help to seal the hubs. This wasn't sufficient though, so we ended up using silicone caulk at the hubs, 8″ out along seams.

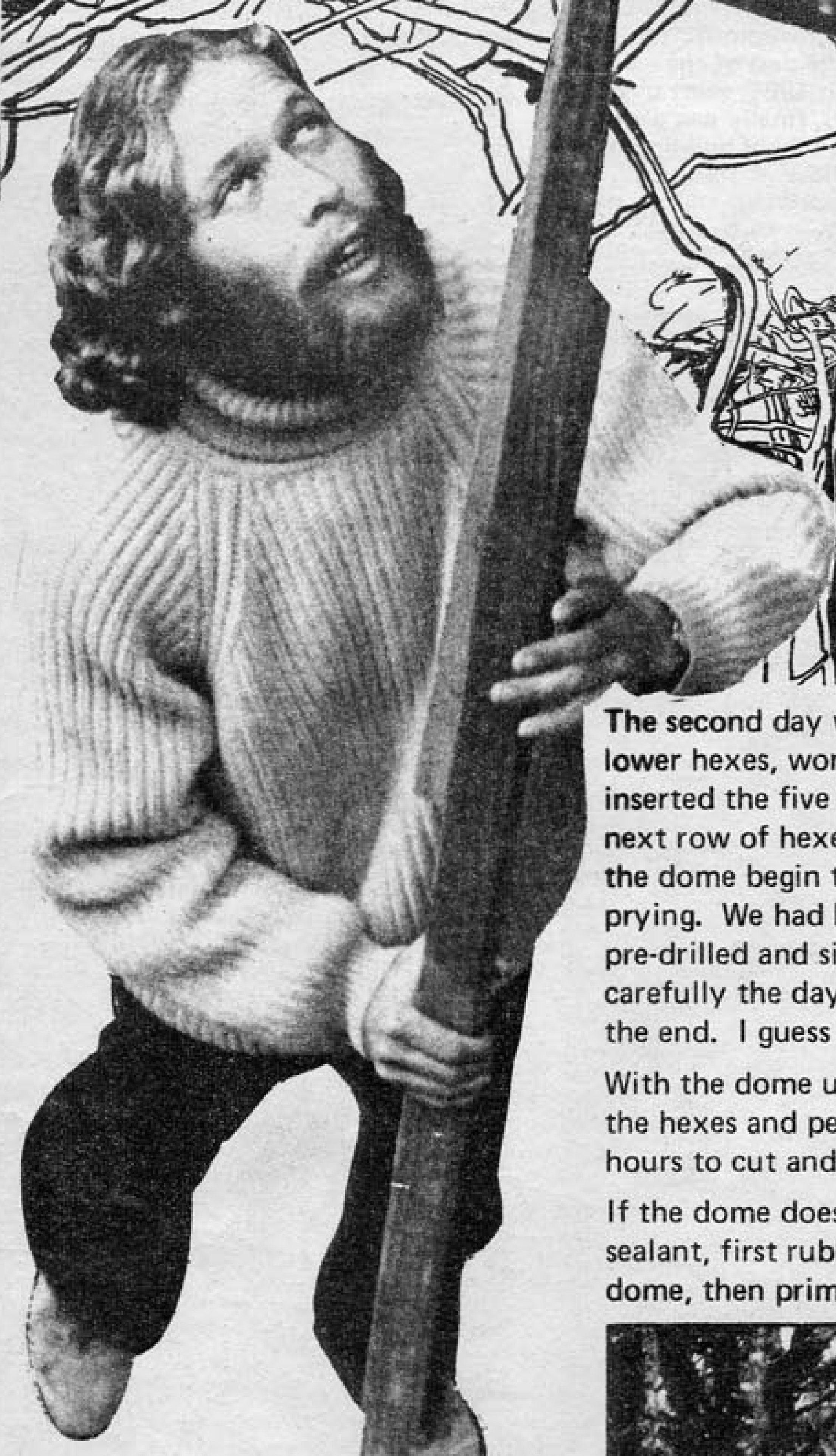
If you should use this method of water-proofing, draw up your own diagram with window pattern, vents, and door. It's natural to think of the dome from the outside looking down when you begin drawing, but do the diagram from the inside looking up since that's how you put the dome up.

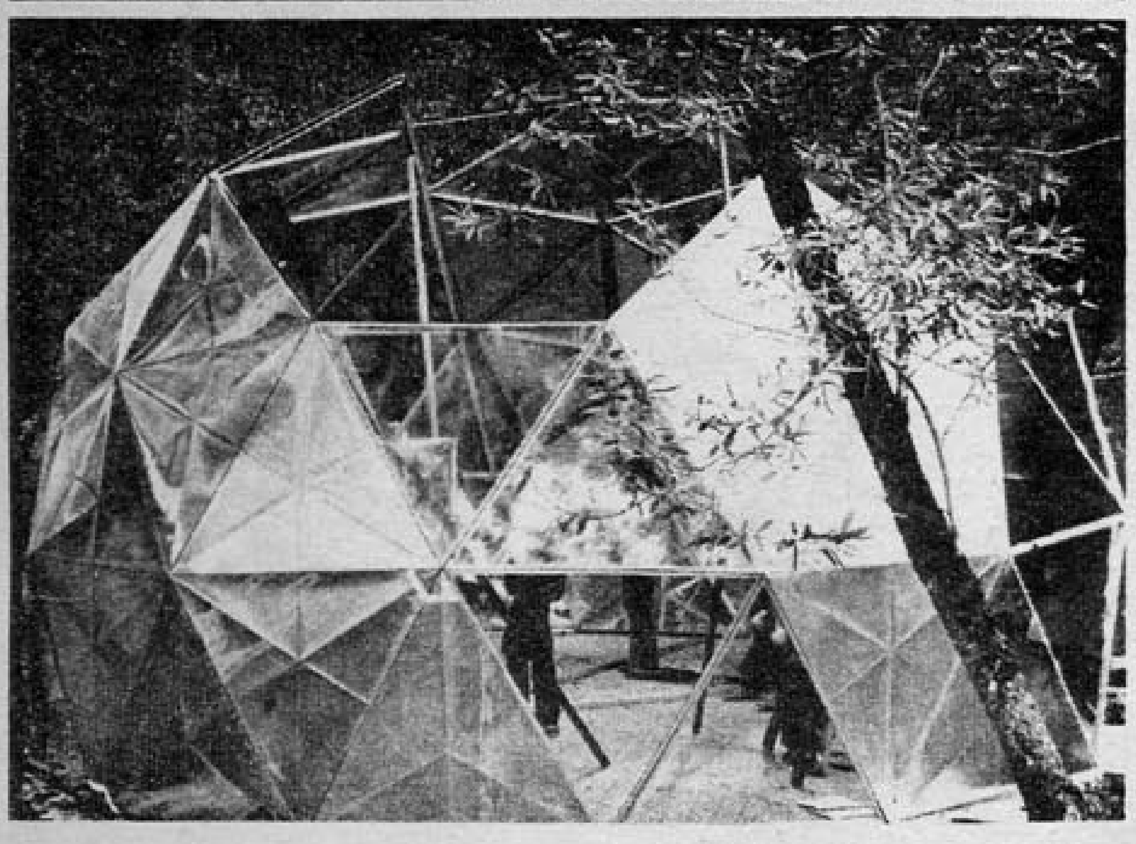






A group of about six people spent the first day putting on the neoprene and assembling hexagons, pentagons and half-hexes. Triangles were aligned and clamped together with several vice-grips. The center hole was drilled first and a bolt inserted before the end holes were drilled. We drilled as close to the corners and as close to the skin as possible without having the bolts angle too much. The bolts were just long enough to fit through the two thicknesses of wood and aluminum, so that even a small amount of angling resulted in having to re-drill the hole. Using slightly longer bolts would have made things easier.



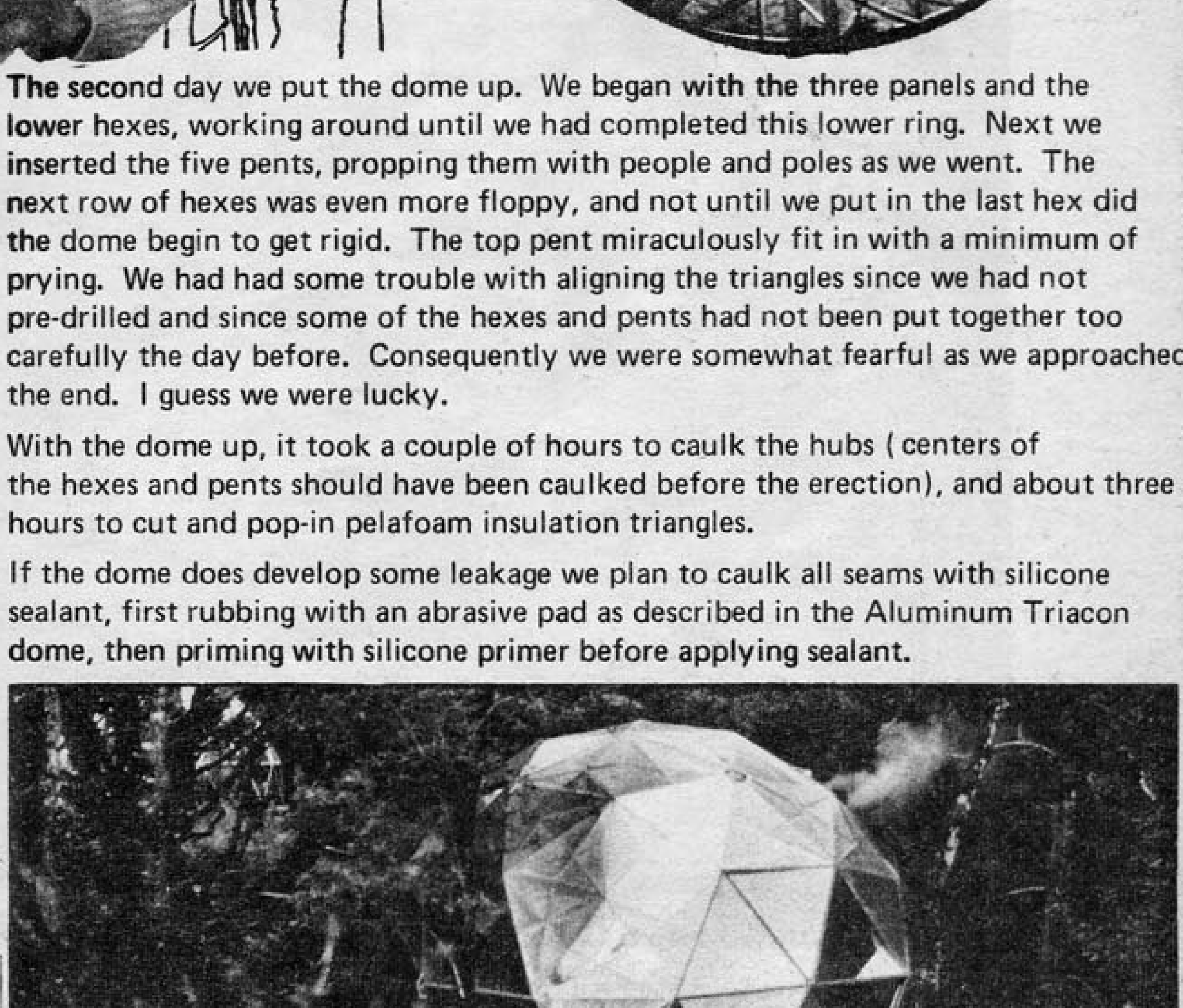


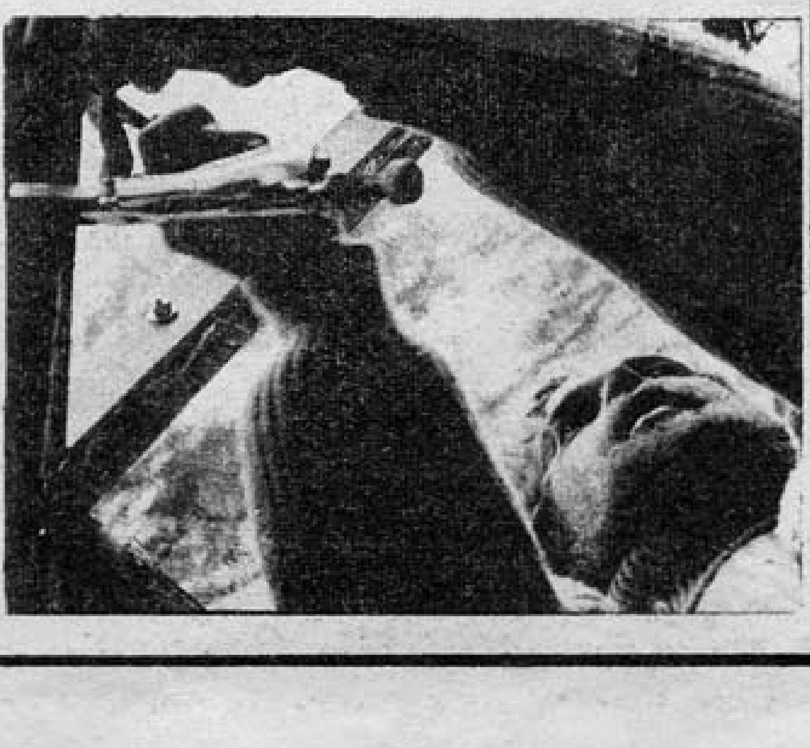
**These problems could have been avoided by pre-drilling.** Our bolts varied anywhere from ½" to 1½" from the skin. Pre-drilling would allow you to place the bolts at a uniform 3/8" from the skin. The dome would be stronger and easier to put up. Putting the bolts closer to the edge will also give you a better seal. Depth of frames was 1¾", depth of flanges was 1-3/8". The width of the neoprene is the only 1" so we positioned it as close to the outside edge as possible without it sticking out when squeezed between the panels.

**The second** day we put the dome up. We began with the three panels and the lower hexes, working around until we had completed this lower ring. Next we inserted the five pents, propping them with people and poles as we went. The next row of hexes was even more floppy, and not until we put in the last hex did the dome begin to get rigid. The top pent miraculously fit in with a minimum of prying. We had had some trouble with aligning the triangles since we had not pre-drilled and since some of the hexes and pents had not been put together too carefully the day before. Consequently we were somewhat fearful as we approached the end. I guess we were lucky.

With the dome up, it took a couple of hours to caulk the hubs ( centers of the hexes and pents should have been caulked before the erection), and about three hours to cut and pop-in pelafoam insulation triangles.

If the dome does develop some leakage we plan to caulk all seams with silicone sealant, first rubbing with an abrasive pad as described in the Aluminum Triacon dome, then priming with silicone primer before applying sealant.





Looking from the outside, the aluminum is outlined by the thin black line of neoprene in the seams. The cross-braking gives decagons around the centers of the pents and 12agons around the hexes. The great circle windows are framed in wood. The only unforeseen problem is that it is under a fairly prolific oak tree. Acorns hitting the dome sound like gunshots and leave small dimples in the aluminum....but then there are only acorns a couple of months a year.

**What the place has been, despite what we write about it, what will be written about it by educators, is a place where kids can come and live with freedom, do as they wish, make mistakes, learn what they want, or do nothing at all. Some have built their fantasies. There are no masterminds, philosophies, guiding forces, or directors, it's just a place to be.**

# PACIFIC HIGH SCHOOL

I'd heard about Pacific off and on for a few years, knew that it was some kind of rebel school, that it was in the Santa Cruz mountains, that a lot of people's trails had passed through the place. Turns out that Pacific is what is called a *free school*, not free to attend, because tuition is high, but free in the sense that there's freedom from institutionalized education, it's an attempt on the part of the founders to make their own school. It started in 1961, went through moves from one place to another, heavy changes, finally was given 40 acres in the Santa Cruz Mountains. The first school buildings were old tin chinchilla barns. Peter Calthorpe and I have written the following stuff, some background of the high school community that sponsored the domes and gave us the freedom to experiment.

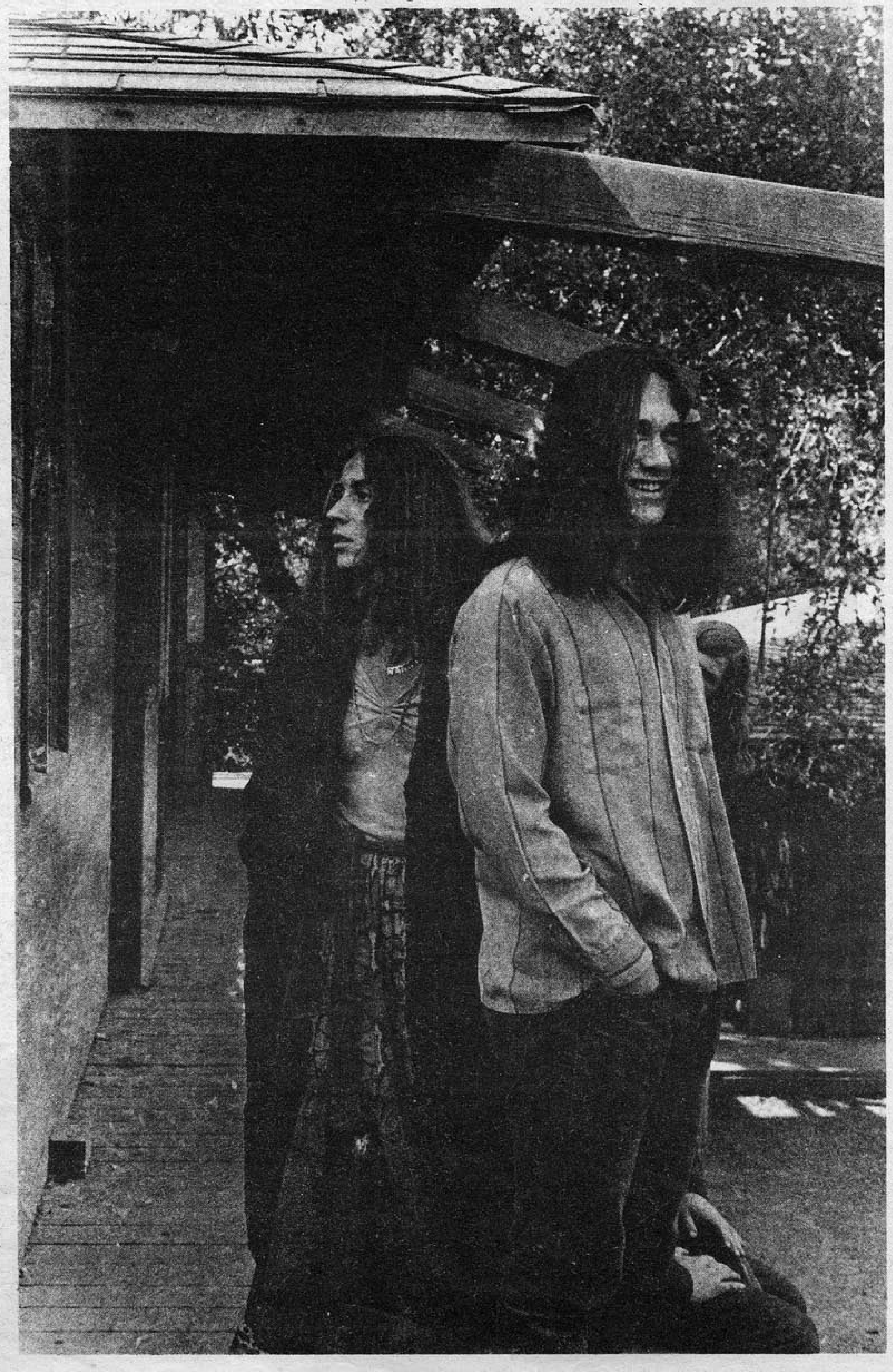
**Three years ago Pacific high school was probably one of the freest places around. We had fourty acres of beautiful land, a lot of close friends, some money, a daily influx of students, and no idea of what education meant or was for. Almost everyone lived in the flatlands and came in busses every day; it was like coming to a little haven of comrads, getting stoned and playing at everything from submarine building to James Joyce. In the winter the rain kept us inside and drove us mad with lack of space and dirt. People started hating each other. It didn't seem worth driving for 45 min. to get to a lot of intense conflicts.**

**Everyone had plans to make the school better (Pacific's greatest trouble has always been its unlimited potential) and all the plans involved firing someone or changing the government or embarking on some sophisticated program of cognitive development. The students fired all the staff, totally reorganized, restructured, the educational process, and went steaming off for a good three weeks of scheduled classes and work lists.**

**Things started to pick up when the weather cleared and we ran out of money. The staff (we had all been rehired) that didn't care stopped coming, the rest started camping out and sharing food expenses. There were less people around and less conflicts, nobody cared really.**

**People had toyed with the idea of making it a live-in school but we were so lame and could barely keep the buses running and everyone out of jail, much less feed and house 60 people. It was the best idea, because everything we were trying to do to give students a sense of independence and autonomy was contradicted by their life at home.**

**By the end of the spring there were about 15 people living on the property and were very high. There was no doubt that students and staff living in a community was the next step. We had a small kitchen running with a new cook every night. People lived in tents, parachutes, trucks, trailers and one beautiful house. The school was really on the edge of disaster; every time I went to the flatlands someone would ask if it was true that the school had folded. So there was nothing to lose (actually, I think the "school" folded 2 years before that time when all those exciting things started happening in S. F.).**



A lot of energy in the west in spring 1968. Alloy in New Mexico, Whole Earth Catalog beginning to click. A bunch of rock freaks dreamed up the Wild West Festival for S. F. summer 1968—rented an old Victorian house as headquarters, started coordinating with the mayor, Airplane, Greatful Dead, Panthers for a weekend of rock music in Golden Gate Park, night concerts in Kezar. We were going to to build a 70' dome framework of conduit, put it up in a glen near the polo grounds, use it for concerts. Cameramen would be able to climb up and film from 40' in the air, hang speakers from it. Green paint outside, blue inside, so it would blend with trees, or sky depending on whether you were in or out.

We were going in and out of S. F. from Big Sur, getting materials ready for the dome. I'd met Jay, who'd spent a lot of time with Fuller and had dome building experience, and we were going to work together on the Wild West dome. On the way back to Big Sur, carrying a dome model in the bus, we met people from the school at Nepenthe, a lot of things in common, excitement, shelter's needed, here's a model. Later five people come to visit us in Big Sur, see the dome there, we decide to build some, we start driving back and forth to the school. Martin and kids make a conduit frame dome, put together on a hot day with funky ladder and beer. School meetings are held outside, under that dome framework. It's a symbol of what's in our heads. Sarah and I getting more and more attached to the people and the place, despite no place to live, no water, hot and dusty dry climate. We pitched a tent on the ridge, looking about 20 miles through rolling hills to the summer ocean fog. Martin lived about 50' away in a pup tent, reading late each night by kerosene lantern. Fresh ground coffee and schemes at Mark's house each morning, swimming in the lake on hot afternoons. Problems seemed insurmountable, but we had nothing to lose. No water, no money, no unifying principles.

Lingerman bros, sympathetic neighbors brought their drilling rig over, started drilling for water a few weeks before school began. At 180 ft still no water, Martin threw I Ching which suggested we keep going, and John hit water at 200'—20 gallons per minute, jubilation!

The school was blindly on its way to becoming a boarding school. Not much was ever planned, things just happened with some kind of hazy group steering. It was too much of a hassle bringing kids up in buses from the valley each day and Mark and Michael started accepting students for boarding even though we had no place for them to live. All along, I'm telling them that domes can be built in a day—the Bucky hype.

Kids and lumber for the first domes arrived about the same time. Fantastic vitality. Energy, movement. We walked around, picked out dome sites. We held an impromptu dome class; everyone came. We went through the D stick model thing, Bucky's trip showing the instability of the cube unless it has a tetrahedron inside. Started building platforms, not even enough time to sit down and work out a radial floor, lot of mistakes, but things were moving. Many people got in on the building, if they wanted to build a dome they'd come around and watch. We went into operation in an old tin building that had housed a horse, and was full of horseshit. We cleaned it out, ran in electricity, saws and drill press went into operation. As struts were being cut, kids would look in to see how. Everyone rushing to get their dome built. Things moving along of their own accord, no one directing. When I look back I see that what happened was a community forming itself, created with no real plan other than the need to live together. No grand design, no master plan. Joys, tensions, both with the vitality implicit in beginnings.

We somehow governed ourselves enough to jointly survive. Community more economical way to live than single family. One sink, washing machine, kitchen for 50 people. An exercise in expanded awareness. Many problems. Your consciousness will change, or you'll leave the group. Your consciousness may change and *then* you'll leave the group, but if you can ride with it for a while, you'll learn a fantastic amount about yourself, and others. So different from anything you've done in the white middle class trip with all roads open to you from birth, color and poverty not wrecking your chances to do something.

The first dome was built for Steve and Sky, due to arrive momentarily from New Mexico. All our mistakes converged on the first dome. We never did get it sealed, and ended up shingling it with tarpaper and red composition shingles.

*Great deal of raw energy, many people have passed through the land over the years. It's a romantic place, blue jays, woods, roads back into into the hills. A half mile walk from the school buildings is the ridge. Walk along a dirt road, trees high above/view down to the sea, three long ridges running down to the Pacific, the air shows the city's southward drifting poison air in the summer, but on a clear cold day after a storm blew in from Alaska fresh December's early rain green grass overtaking last summer's wheat straw. Clouds moving in large segments suns rays shining thru clouds, streaming down around trees on the next ridge out.*

The place is governed by weekly meetings. With so many people, so many trips, there's little coherence. Half of the meetings are shout-outs. As intense as the joys are the problems of living with 60 people. Everyone is alternately loving the place and ready to pack and leave.

We knew we had to deal with the building inspector so invited him up one day. We spent the entire previous day cleaning up, hiding the illegal shower, everyone was hipped to his coming. The place never looked so clean, we showed him Steve's submarine—Steve had been working on it for a year, out of oil drums, yellow with scalloped red fins, Cindy faithfully bringing him food and wrenches, kids with the freedom to build their fantasies.

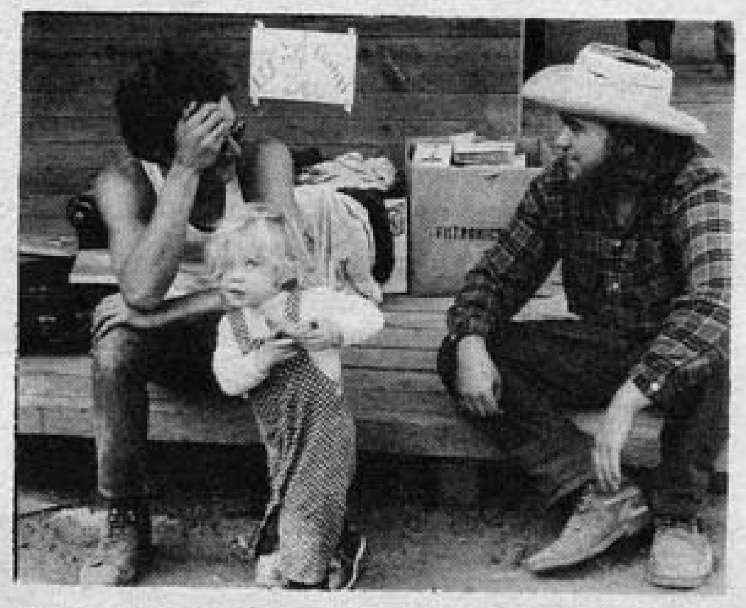
Told the insp we were going to experiment with domes. Somehow it came out in the conversation that an exception to the bldg codes were organized camps, and tent structures. Some research and we knew this was our only chance to build the domes. No freedom in Calif like in New Mexico, but here's a loophole. We decide to go ahead. We've got seven domes built by the time someone reports us and we get the inevitable call from insp. We're half-way within the law, as we've told them what we were going to do, it's the Pacific High School fait acompli, and through maneuvers over the months, some good human beings in Santa Cruz county departments we somehow become semi-legal. We've stretched the rules, but officials may not be too eager to close down a community of kids who have built their own shelters and are looking after themselves.

I'd started writing a book about dome building in Big Sur, after Alloy, and had stuff written on the sun dome, Big Sur dome, and floors. As we started building at the school I kept notes, on paper bags, anything lying around, throwing them all in folders. Our idea at the school was to have a group watch us build, then they'd know how to do it themselves, and later, they'd teach others—like a relay race, passing the baton.

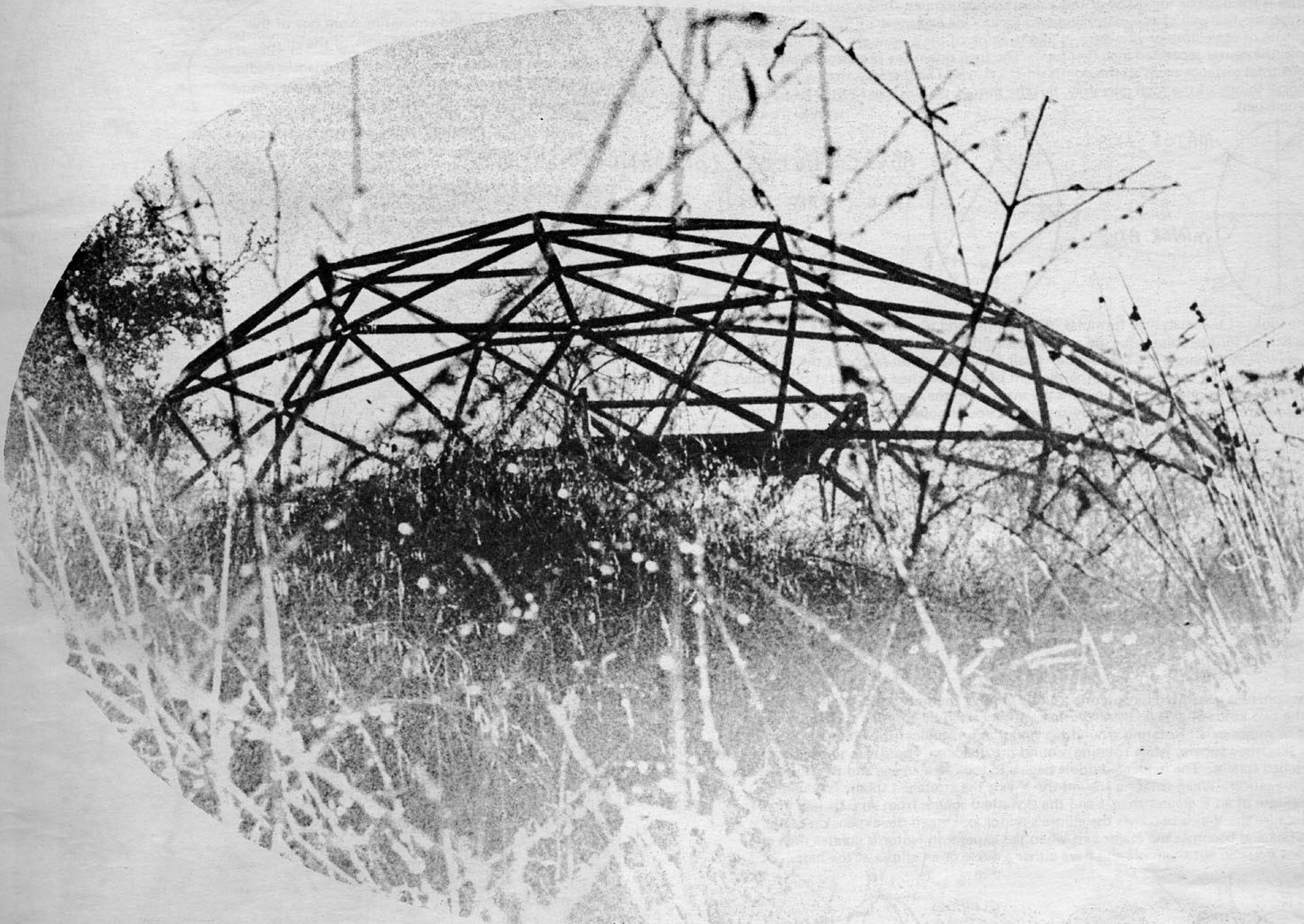
Probably through the Whole Earth Catalog, dome builders all over the country found out what we were doing, started writing, asking for information, and pressure for a domebuilding book began to mount. Obviously more efficient to take the time to publish, rather than write hundreds of individual letters.

Wayne took over the building of plywood domes, Jay and Kathleen got immersed in building their pillow dome, Alan and Heath worked by floodlights. Martin got into a saga building his pod, kids frantically trying to throw together their own shelters. Seven or eight domes got built, different degrees of funk, in a few months time. As winter came we started writing, trying to pull our experience and everything coming in thru the mail together. No electricity, writing at night by kerosene lanterns. Slogging through the mud in rubber boots (we get over 60" rain each year). Jonathan wrote the Geodesic Geometry section on a crumpled paper bag. Peter Ross was taking photos now and then as we built. Jack Fulton came down for about two days to shoot film, and printed most of the photos in two marathon days in the darkroom, doing the cover at about 3:00 a.m. the last day of printing.

Finally in March we had it as together as it would ever get, Stewart loaned us the Whole Earth production factory, Bob Easton came up to help thinking we were going to do a mimeograph booklet, and in two weeks we put together *Domebook One.*

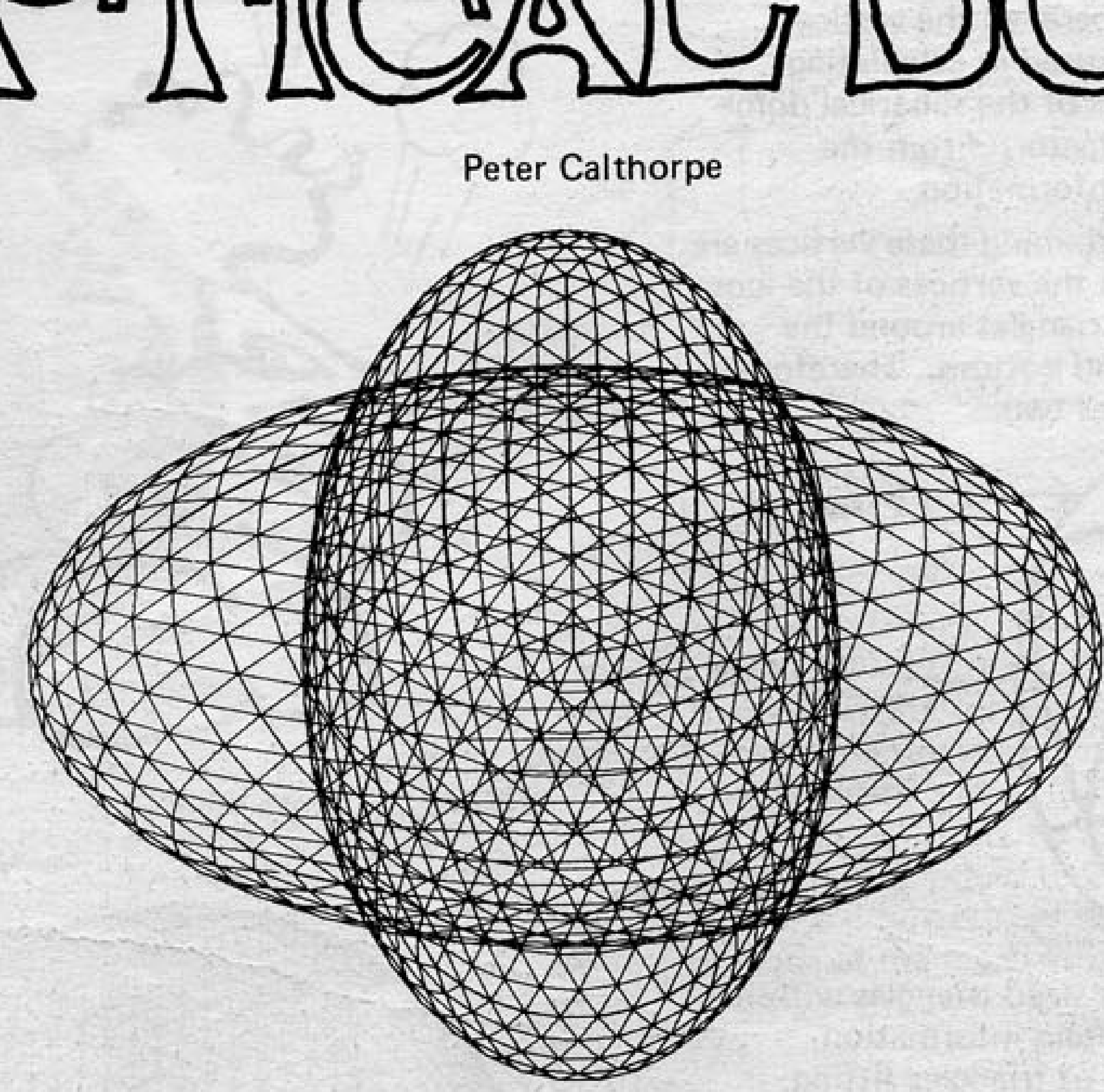


Summer hot and dusty, a lot of flies, we get the roll of aluminum and begin thinking what to do with it. Peter's returned from England, running around doing three things at once. I think I'll build a pod, no I'll do a triacon, hey think you could stretch a dome think that would work? Jonathan's conducting messy fiberglass experiments, calling Abe Shuster, there aren't many people around, it's relaxed and easy. But fall's coming and 65 kids to live there. Kitchen and dining room remodeling starts, it gets done like everything else, in about two months, half assed and worst of all it's not like the old dining room which looked out on trees. When school starts to my horror I find we've built a mess hall, like the army carry your plate past a counter where food is dumped on it. Too many people on the land, the price of success, Mark who digs farms and the country senses it, feels the heaviness of so many people. The excitement of building isn't there any more, meetings aren't as violent, the juice just doesn't seem to be there. Yet the land is still beautiful, land you walk miles over. It begins to feel like time to move...



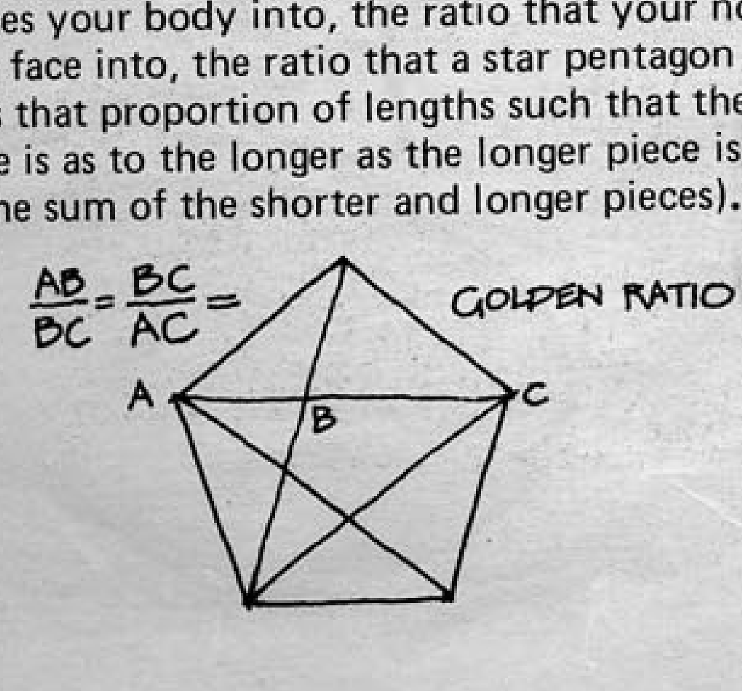
# ELLIPTICAL DOMES

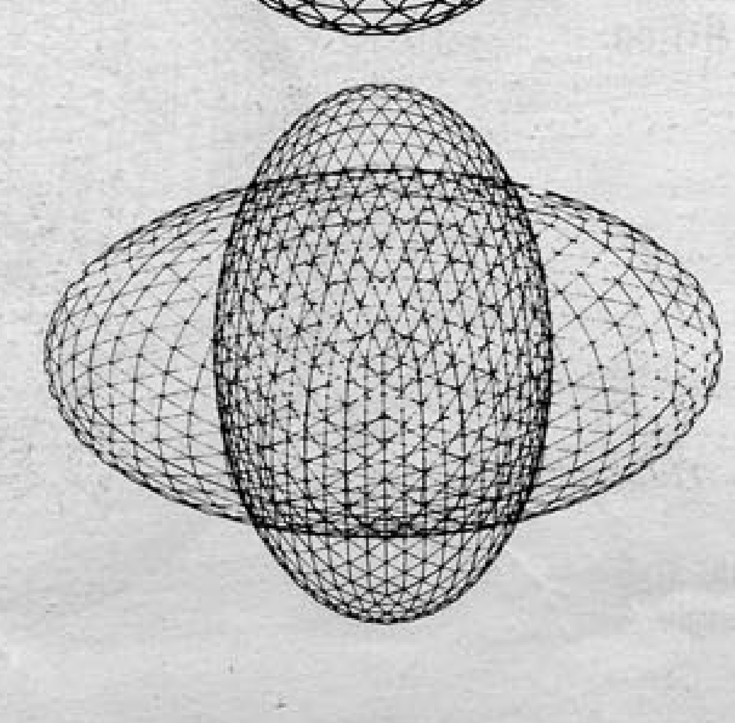
Peter Calthorpe



These nonspherical domes happened because the platform built was too small (16 ft) for a spherical dome. With an 8′ radius the dome would have curved in too fast. So I started stretching and distorting the structure to fit the situation.

You can stretch the sphere into any proportion desirable; I used the golden section which is one of those majic ratios which seem to happen everywhere. It is the ratio that you divide a guitar string into when you play a fifth (which is the most harmonic note), it is the ratio that your belly button divides your body into, the ratio that your nose divides your face into, the ratio that a star pentagon cuts itself into, is that proportion of lengths such that the shorter piece is as to the longer as the longer piece is to the whole(the sum of the shorter and longer pieces).

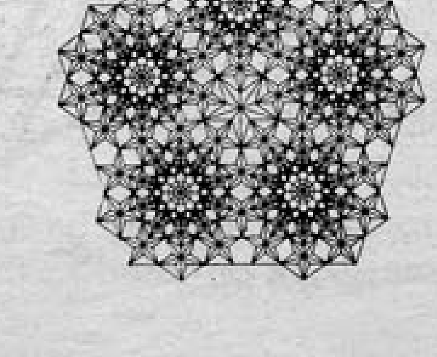


The geodesic dome has produced a building technology which can be applied to any shape. The basis of classical building is that walls and roof are segregated; the pillars become the essential weapon in the fight against gravity (boxing). Dome type construction integrates the structure into a continuous surface and distributes the forces by triangulating the convex curve (judo). Curves are always stronger than planes.

We built a stretched-up dome on a small platform and got some space for a loft. Some of the symmetries disappear, the the triangles become varied, and the space is easier to divide up. A larger stretched dome was built on its side because it looked very bazar as a model.

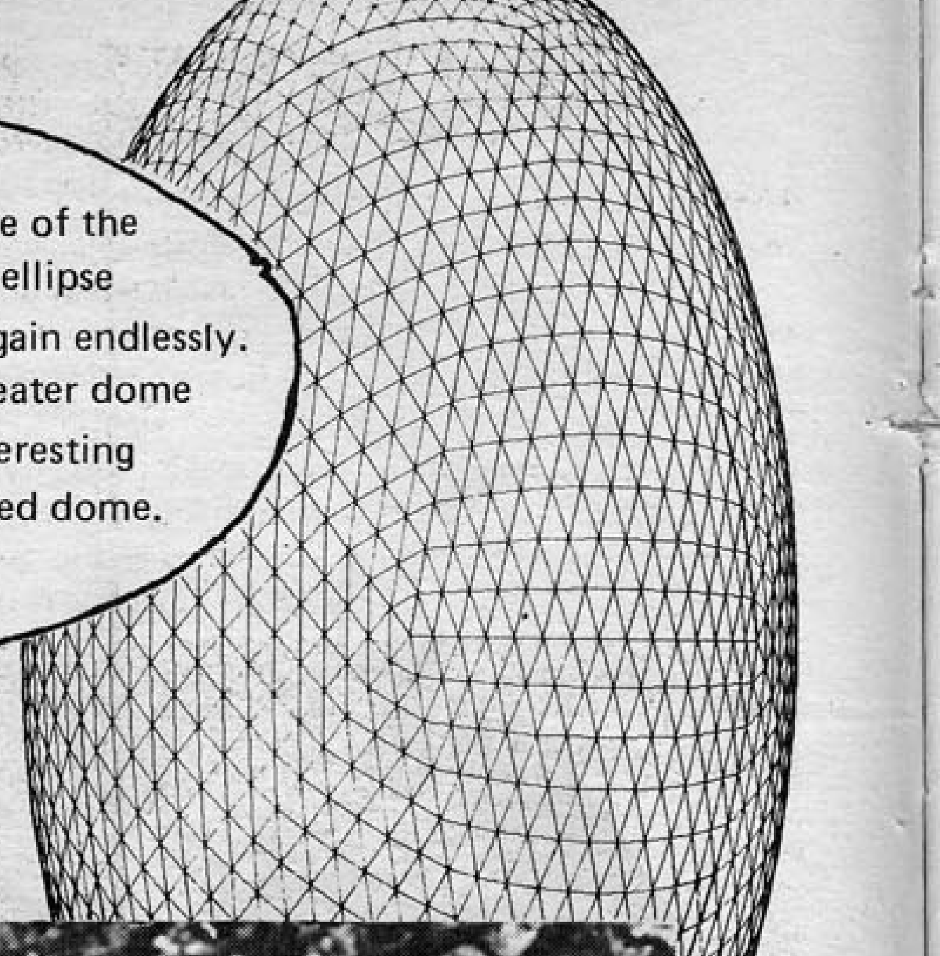
from Patterns in Space



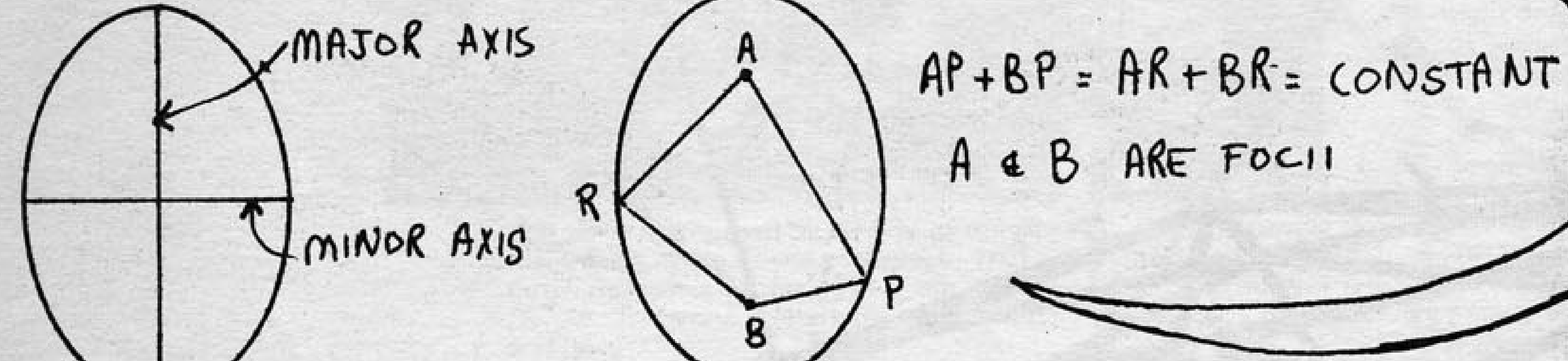
# ELLIPTICAL DOMES

## MATH

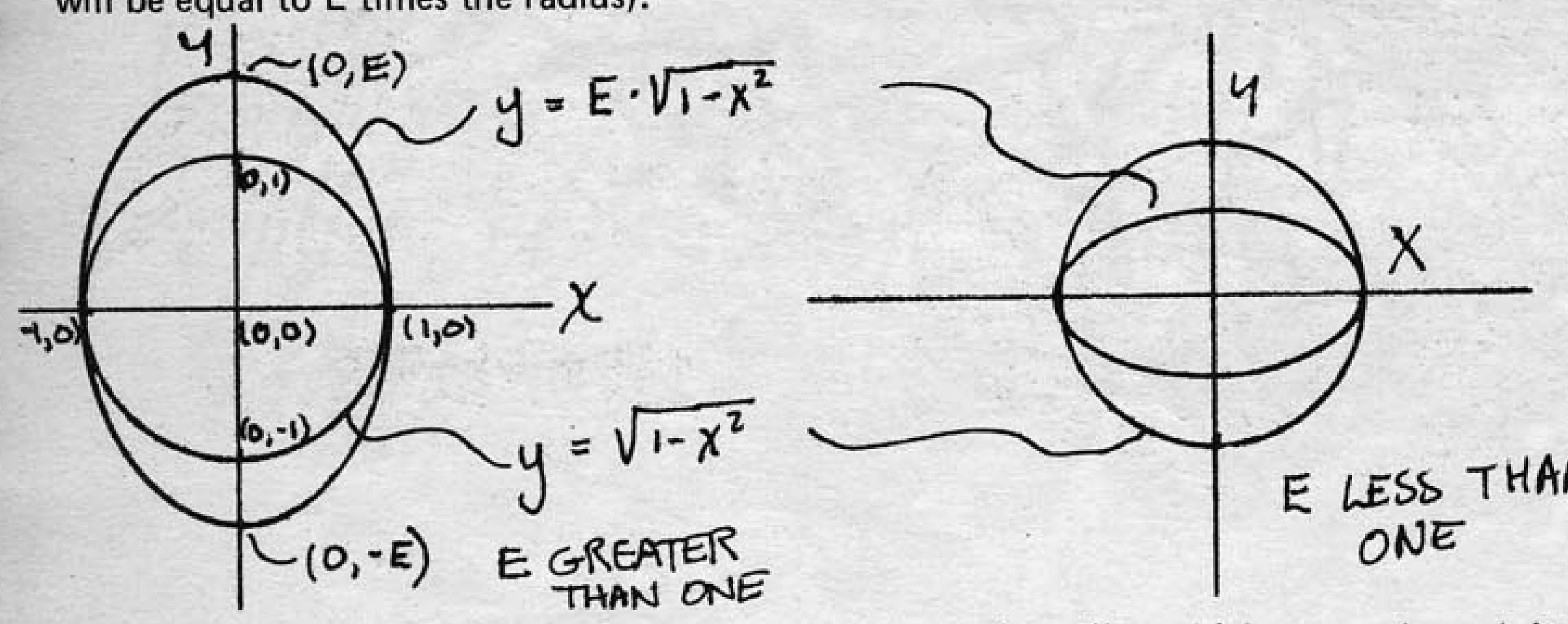
The ellipse is the basis of the shape of these nonspherical domes. It is a two dimensional curve which has two axii of symmetry and two focii. One can think of the circle as a special case of the ellipse or visa versa. I like to think of the ellipse as a schizophrenic circle with the center separated into two focii. The focii retain the property of being a constant total distance from all the points on the curve. The distance from a point on the curve to one of the focii may vary, but the sum of the distances to the two focii remains constant.



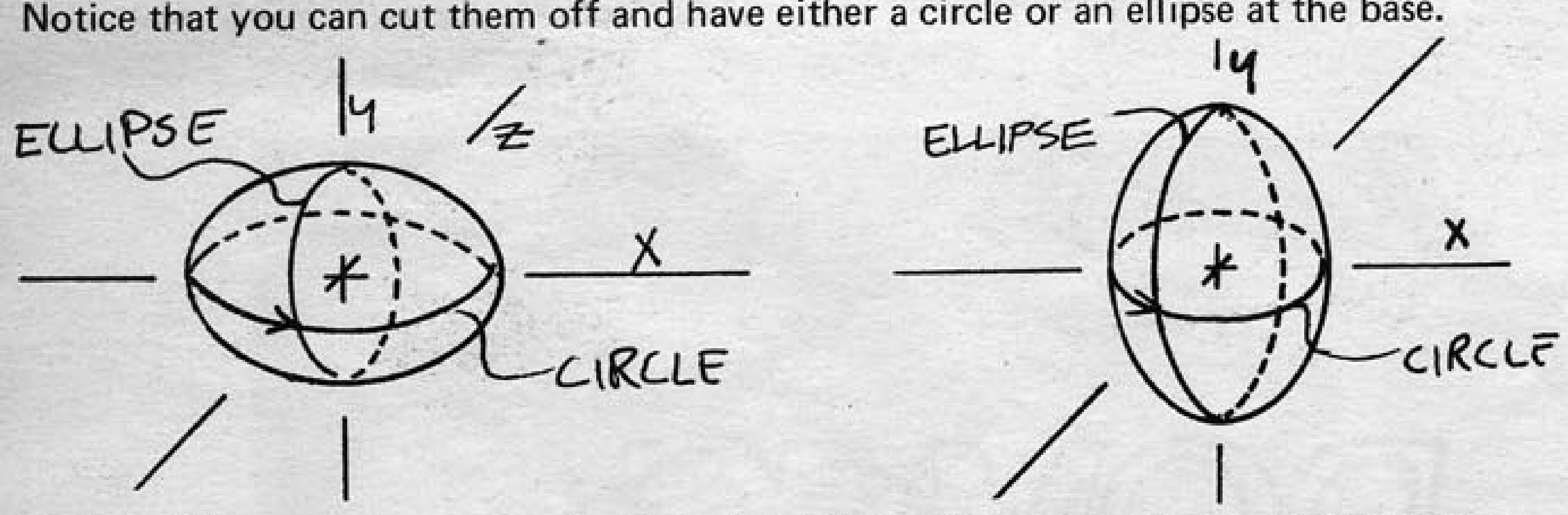
Any light or sound emanating from one of the focii will be reflected off the sides of the ellipse through the other focii and then back again endlessly. This means good sound projection for a theater dome (stage at A and audience at B) and interesting possibilities for a mirrorized dome.




When one looks at the analytical formulas of the ellipse and the circle they are exactly the same except for one value: for the same X-coordinate the ellipse's Y-coordinate is E times as large as the circle's Y-coordinate. I call E the *expansion factor;* if the expansion factor is greater than 1 the ellipse can the thought of as a stretched circle, if it is less than 1 it is like a skwashed circle. All calculations are made with the X-axis equal to 1. The chord factors are therefore multiplied by the radius you choose for this X-axis(the Y-axis will be equal to E times the radius).



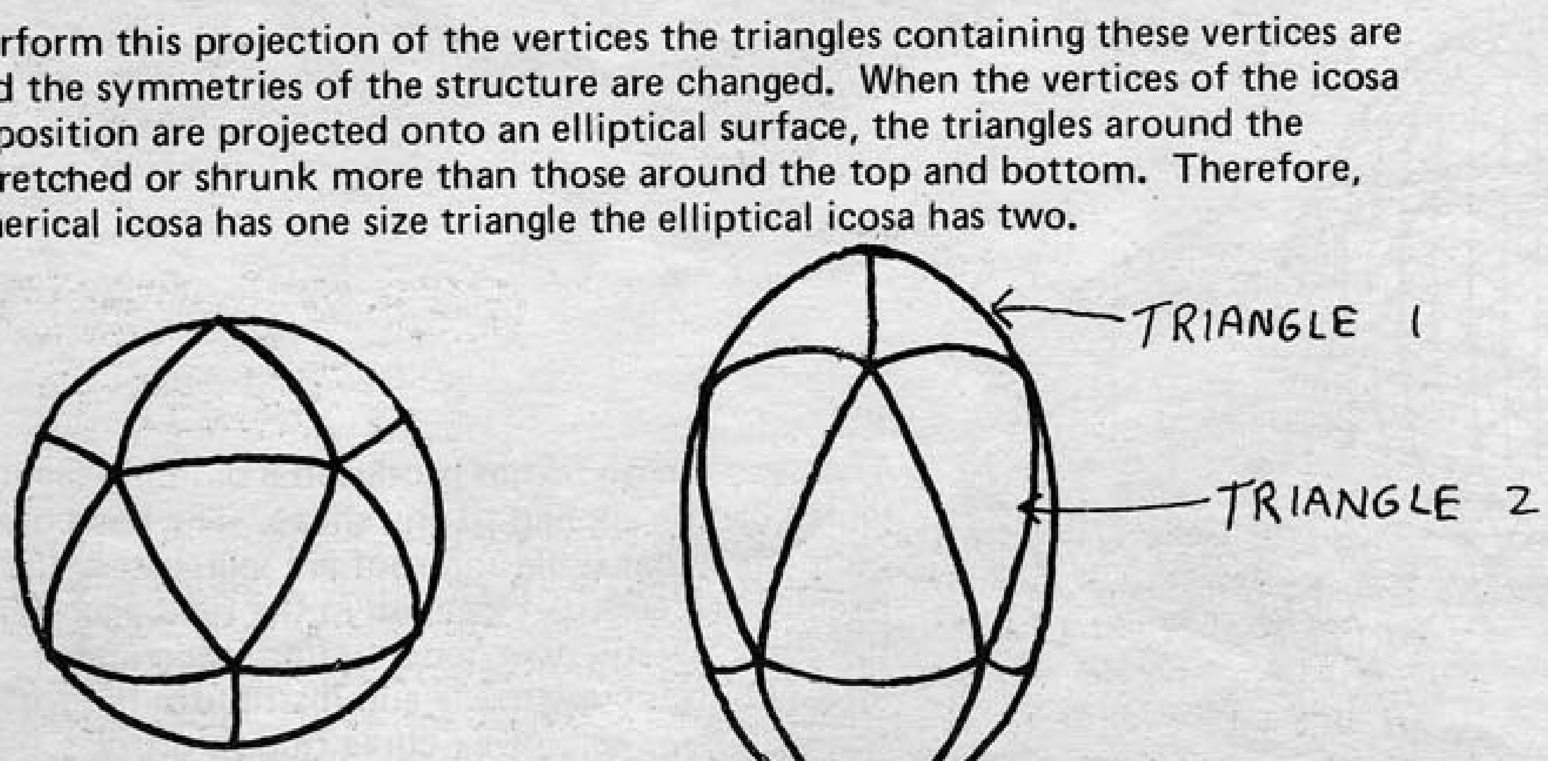

While the sphere is generated by rotating a circle around any line which passes through its center, the two kinds of *ellipses of revolution* are generated by rotating the ellipse around its major or minor axis. Rotating around the minor axis produces the oblique spheroid, or simply a skwashed sphere, while rotating around the major axis results in the acute spheroid, or a stretched sphere. The expanded dome begins to look like an egg and the skwashed one like a flying saucer. When rotating around the Y-axis the stretched sphere is generated from an ellipse of an E greater than 1 and the skwashed sphere from an E of less than 1. This is because the Y-axis becomes the ellipse's minor axis when the expansion factor is less than one and becomes the major axis when the expansion factor is greater than one. Notice that you can cut them off and have either a circle or an ellipse at the base.

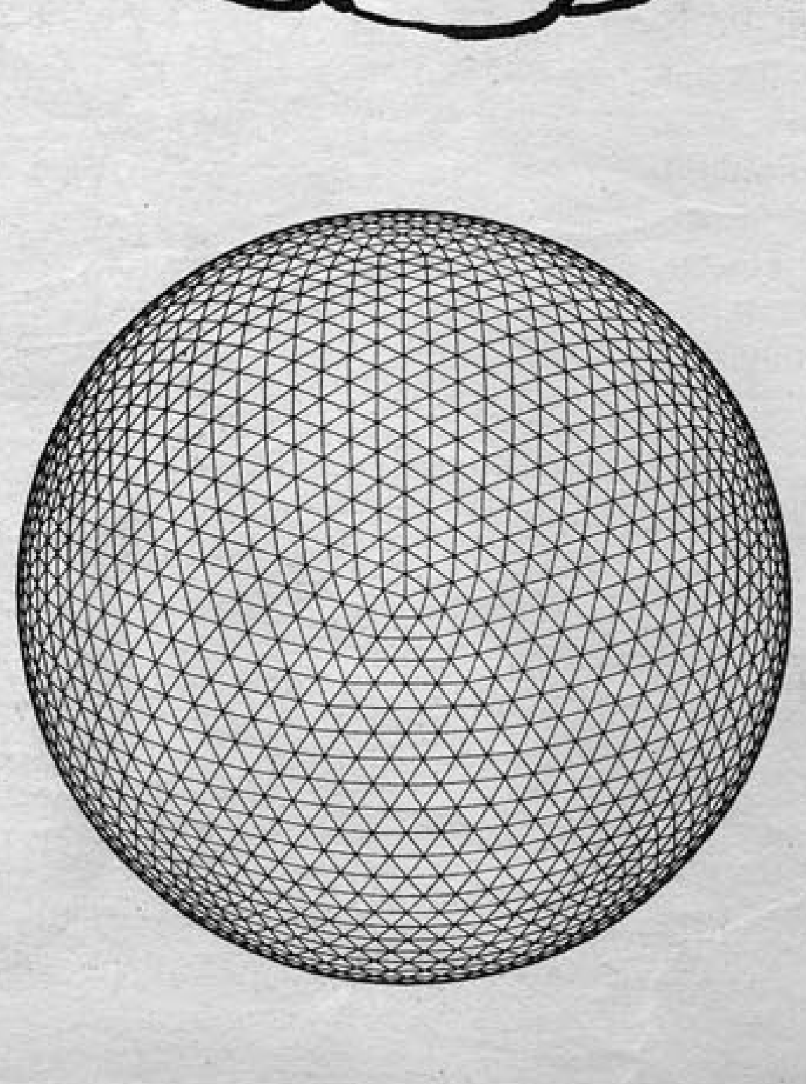


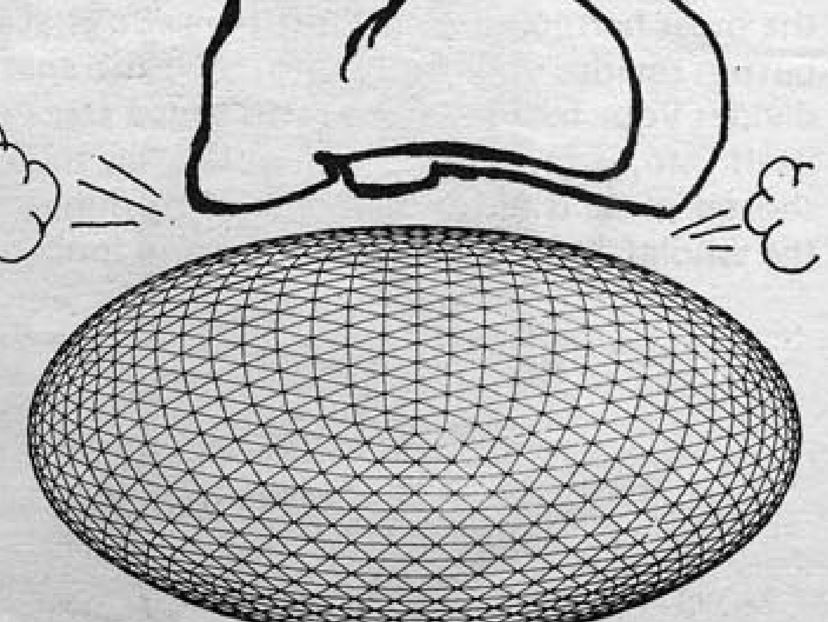


Just as all the vertices of a regular dome lie on the surface of a sphere, all the vertices of an elliptical dome lie on a surface of revolution. The method I used in calculating the chord factors, axial angles, etc. involved projecting the vertices of the spherical dome onto the surface of an ellipse of revolution for chosen expansion factor. From the modified 3-d coordinates of the vertices, I calculated the needed information.

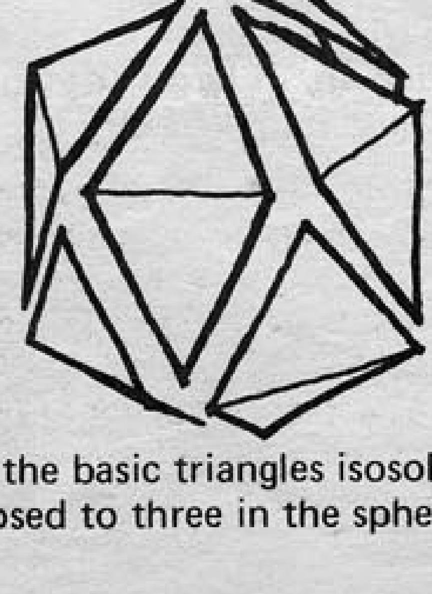
When you perform this projection of the vertices the triangles containing these vertices are distorted, and the symmetries of the structure are changed. When the vertices of the icosa in vertex up position are projected onto an elliptical surface, the triangles around the middle are stretched or shrunk more than those around the top and bottom. Therefore, while the spherical icosa has one size triangle the elliptical icosa has two.





This also means that any further breakdown will result in different sized triangles within these two basic triangles. This why the tables of chord factors contain information on two triangles. The icosa can be thought of as ten of these pairs of triangles fitting together like this.

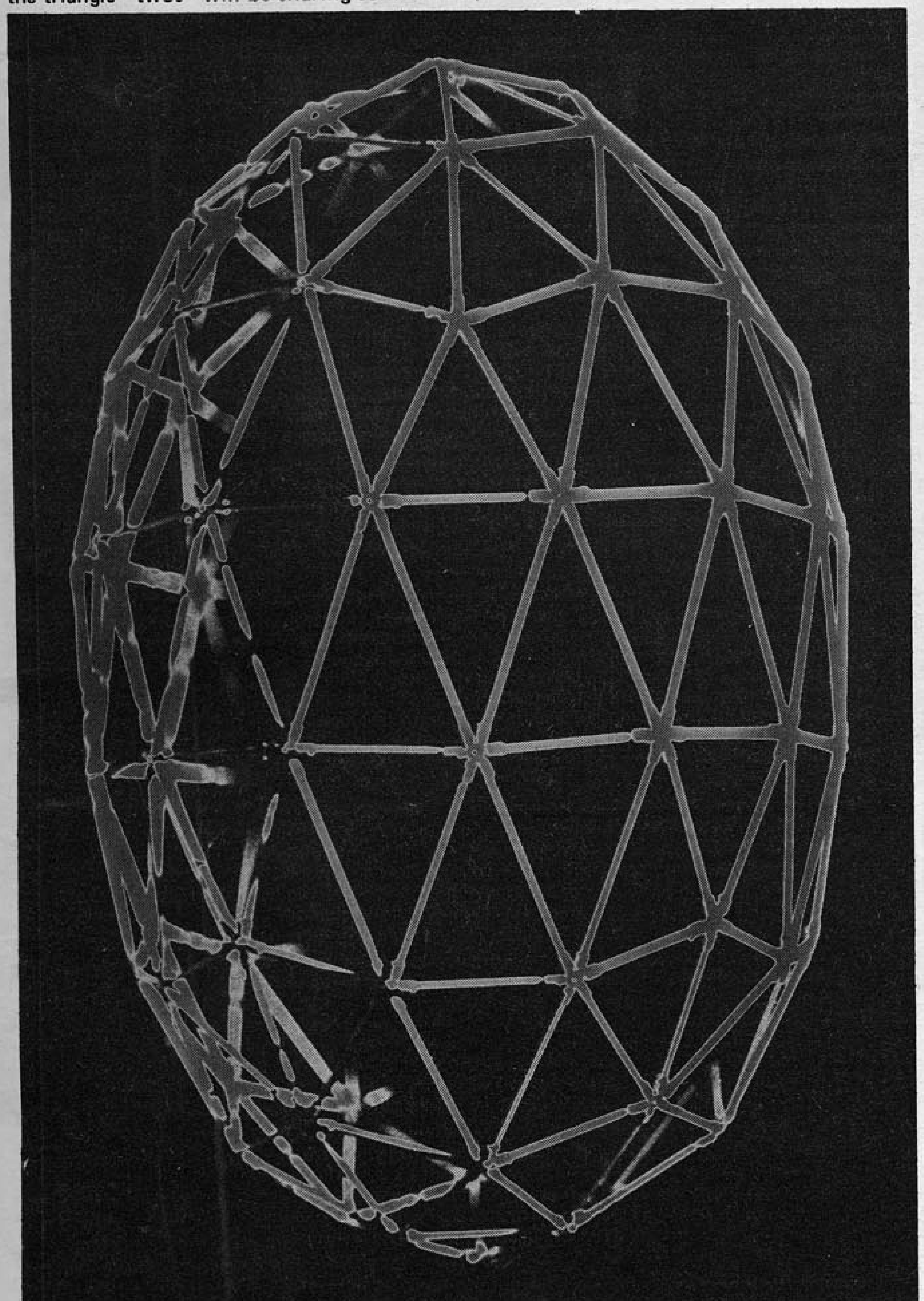


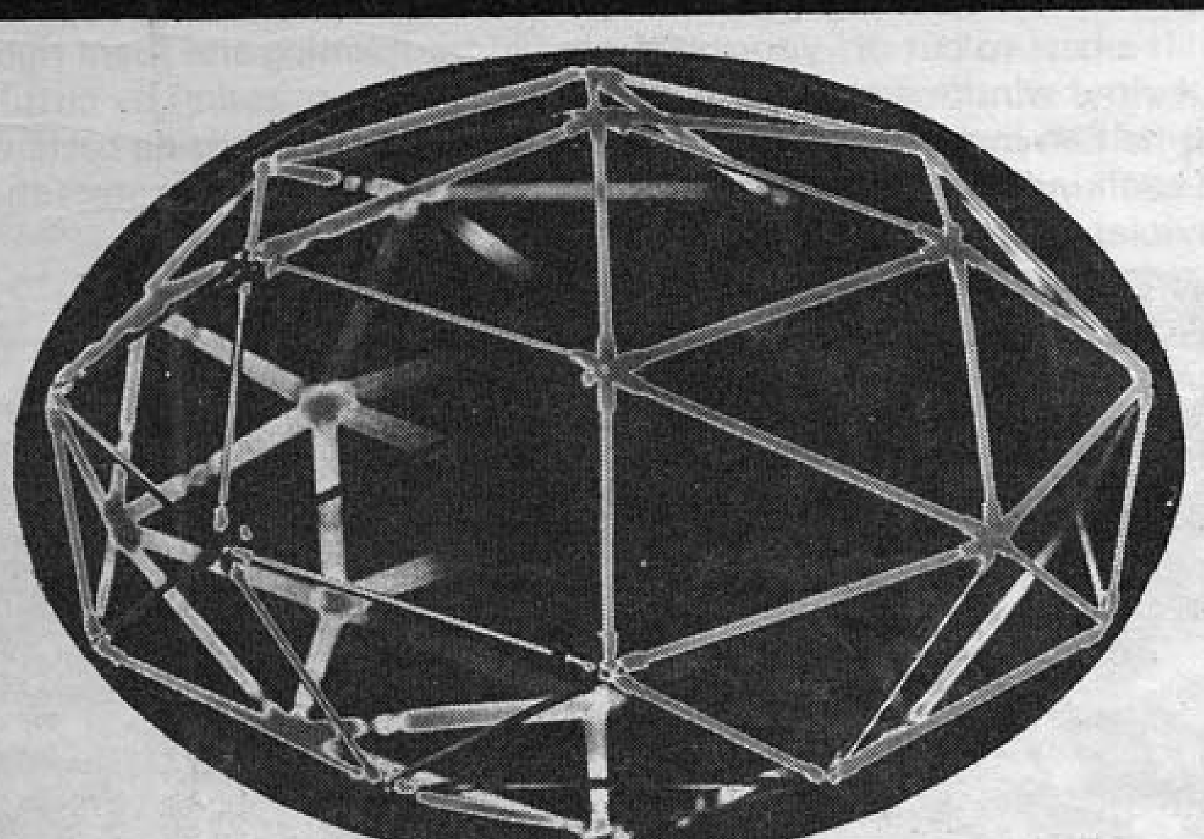
Furthermore, the distortion makes the basic triangles isosolese which means that there is only one axis of symmetry, as opposed to three in the spherical basic icosa triangle.

# ELLIPTICAL DOMES

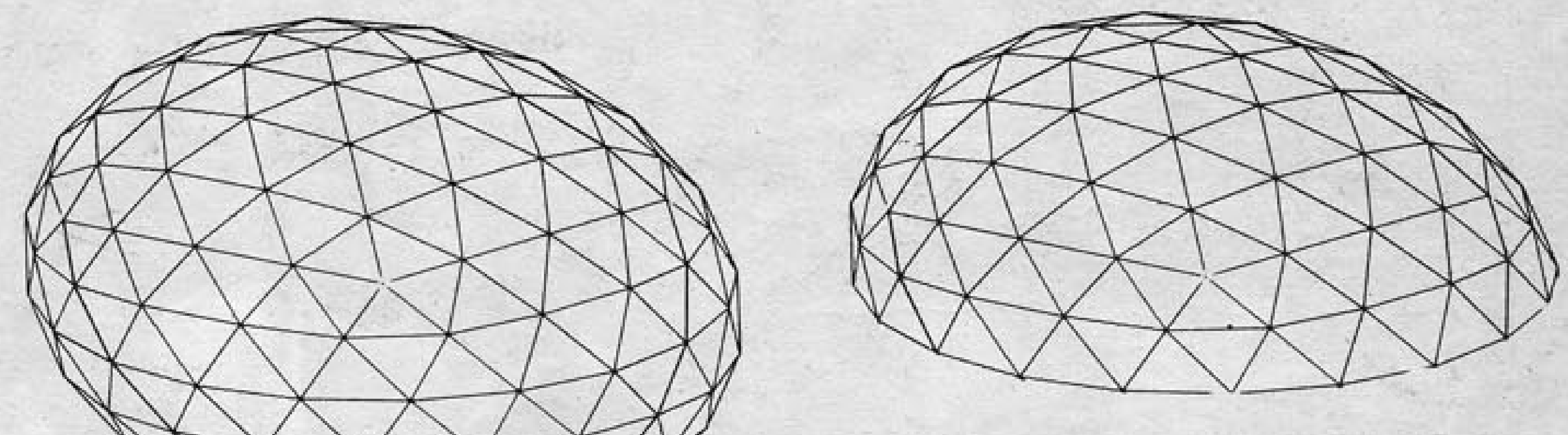
## MODELS

Making a model is absolutely necessary for understanding this type of dome. The number of struts and the overall positioning of hexes and pents remains the same as with a sphere, while the distorted lengths create the new shape. To figure out the number of each strut to cut, remember that there are ten of each of the basic triangles; unless the strut is used twice in one triangle cut ten—if it is not on the edge of the basic triangle or on, or across, the axis of symmetry, then the strut happens twice and you should cut twenty. Keep the struts labeled and bundled to avoid endless confusion. Put together five of the triangle "ones" into a pentagon and add five triangle "twos" to the vacant side, repeat this process for the second half of the dome(remember that the triangle "twos" will be sharing some struts).

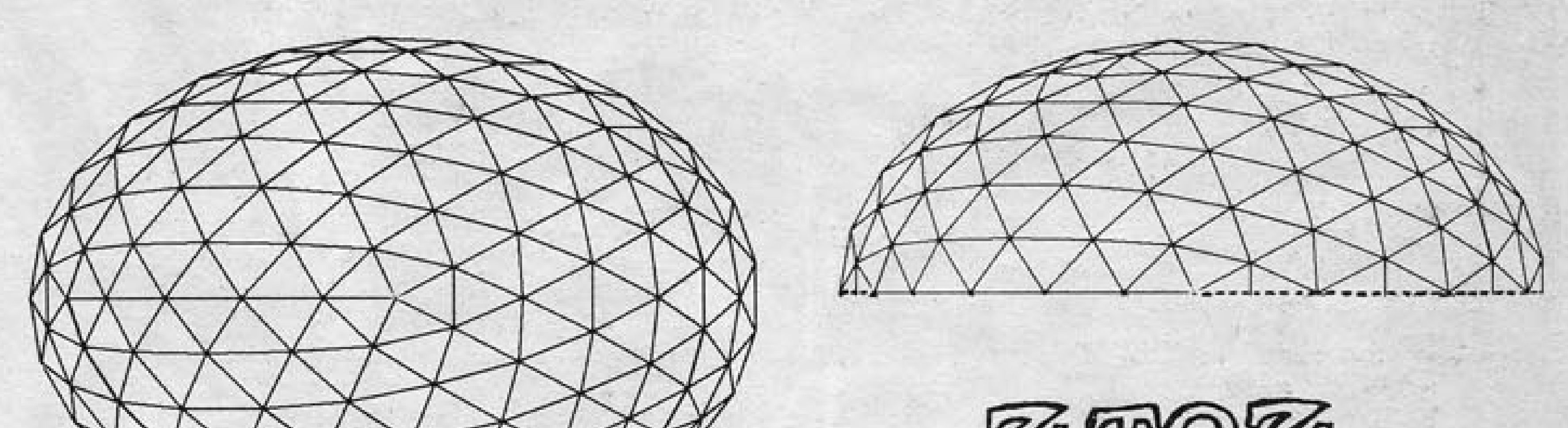




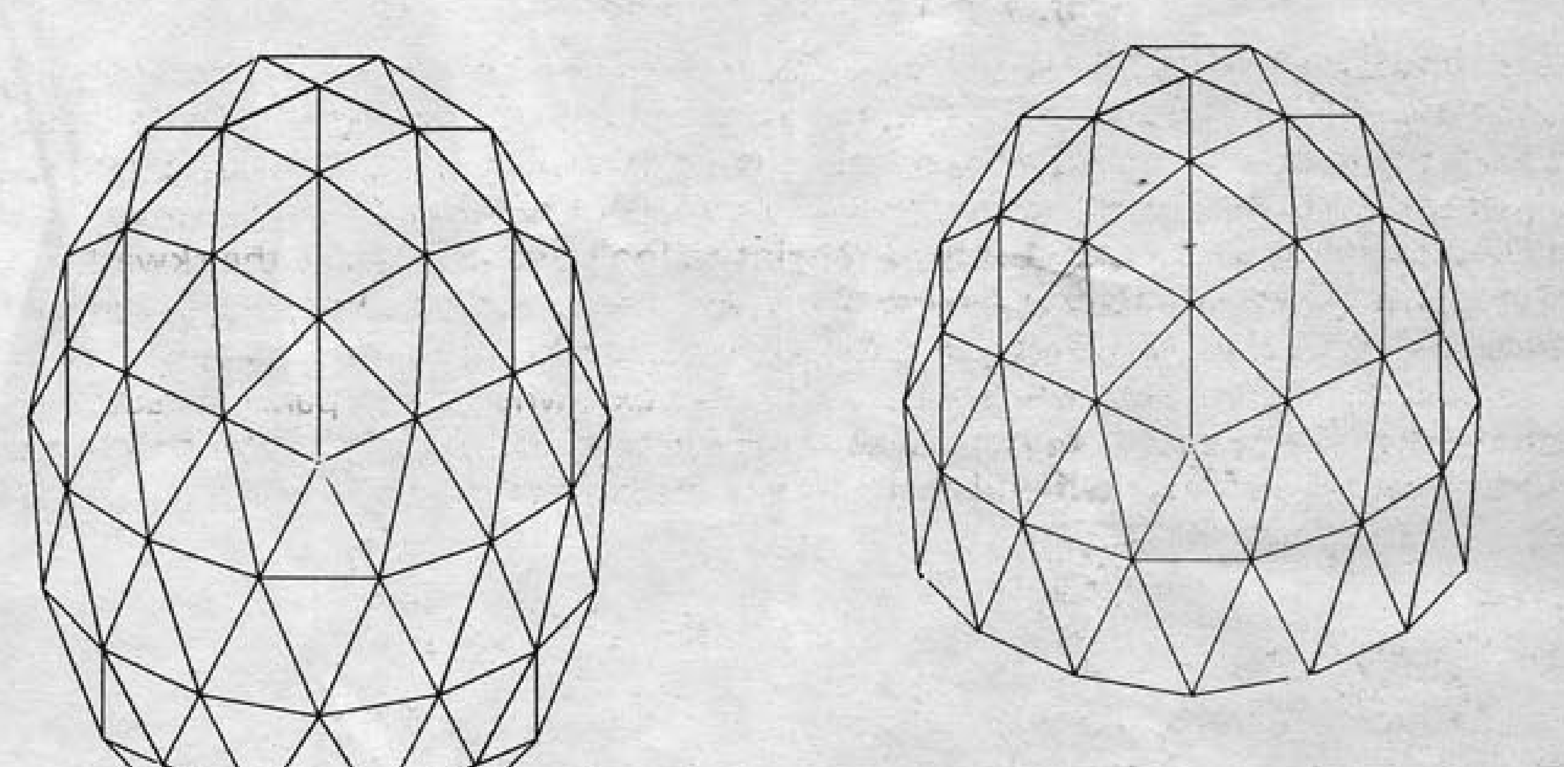
The stretched domes can be used as multi-story structures when truncated on the minor axis (X-axis). The alternate can be truncated along a diagonal (like Zapoche dome) to give an elliptical floor and a whale-like appearance. It can also be sliced zenith to zenith(Y-axis) which involves cutting some of the triangles in half. This gives an elliptical floor and a more symmetrical space. The triacons can do the same things the alternate does except the diagonal slice; all truncations of triacons involve cutting triangles.



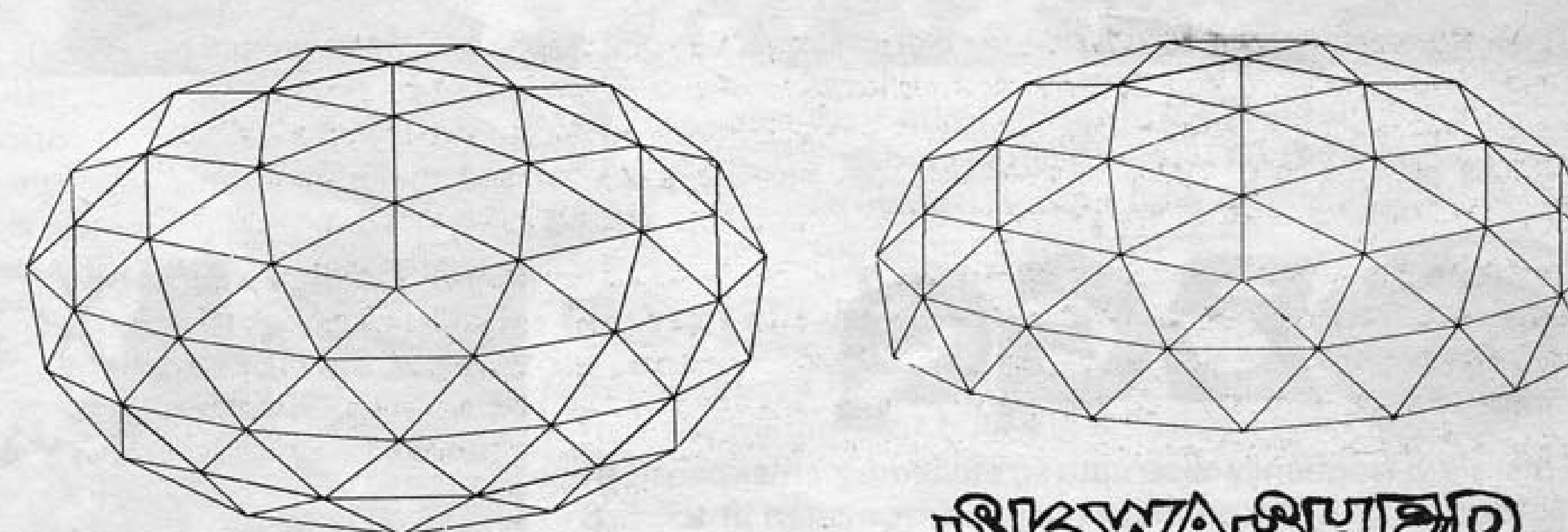
ZAPOCHE



Z TO Z

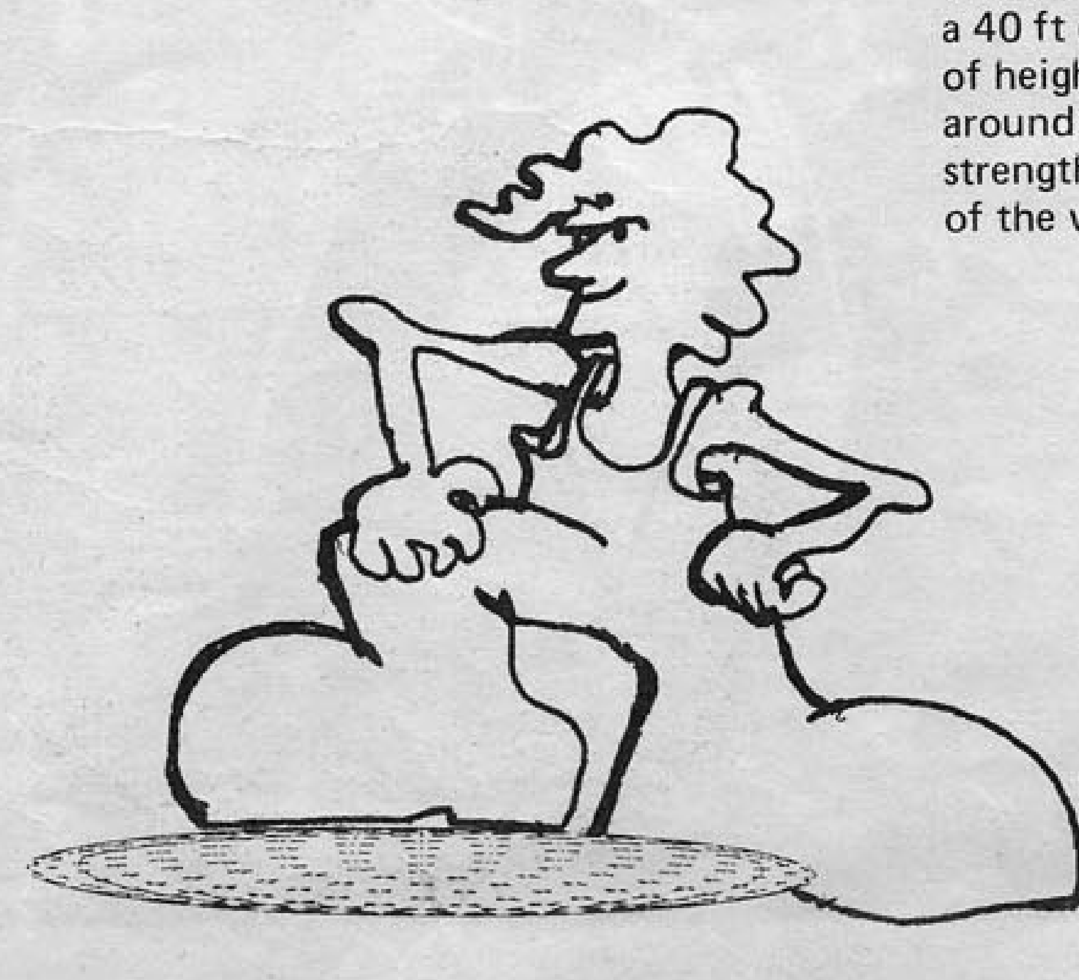


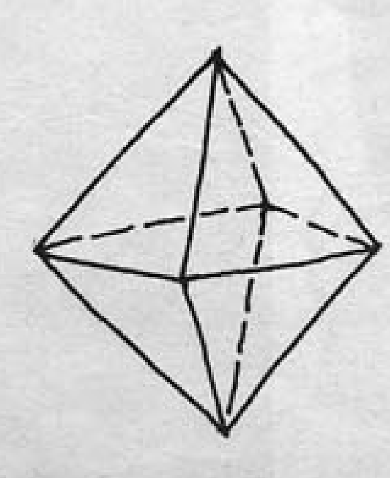
EGG



SKWASHED (ZAFU)

There are many different truncations possible resulting in many different types of spaces. The skwashed dome when truncated along the major axis (the X-axis) produces what could be a large dome without excess head room. If you were interested in,say, a 40 ft dome without a second story, these chord factors would result in about 12 ft of height as opposed to 20 ft in a spherical shape. It also seems good because the struts around the bottom are shorter and therefore stronger than the ones up at the top, the strength of the lower struts being a problem in larger domes, because they carry most of the weight.

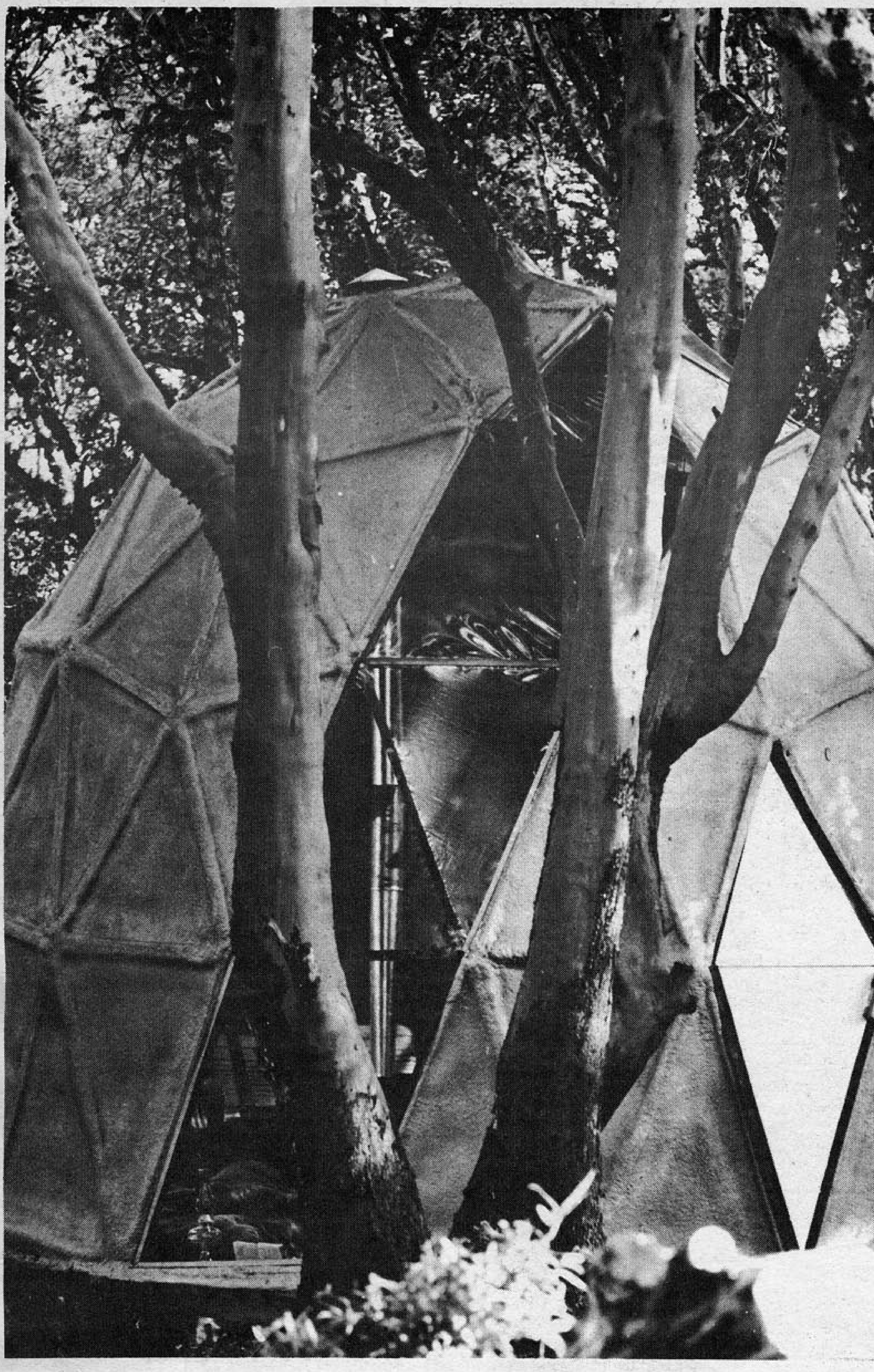




Domes based on the octahedron are simpler in form and truncation than those based on the icosa. The patterns they form, however, are not as beautiful. A nonspherical dome based on the octahedron would have only one kind of triangle, and perfect truncations through the major and minor axii. Because the octahedron has only 8 triangles, compared to 20 in the icosa, the breakdown must be higher to get reasonably sized triangles and a good approximation of the surface.

See p. 112 for tables of data for all these types of domes.

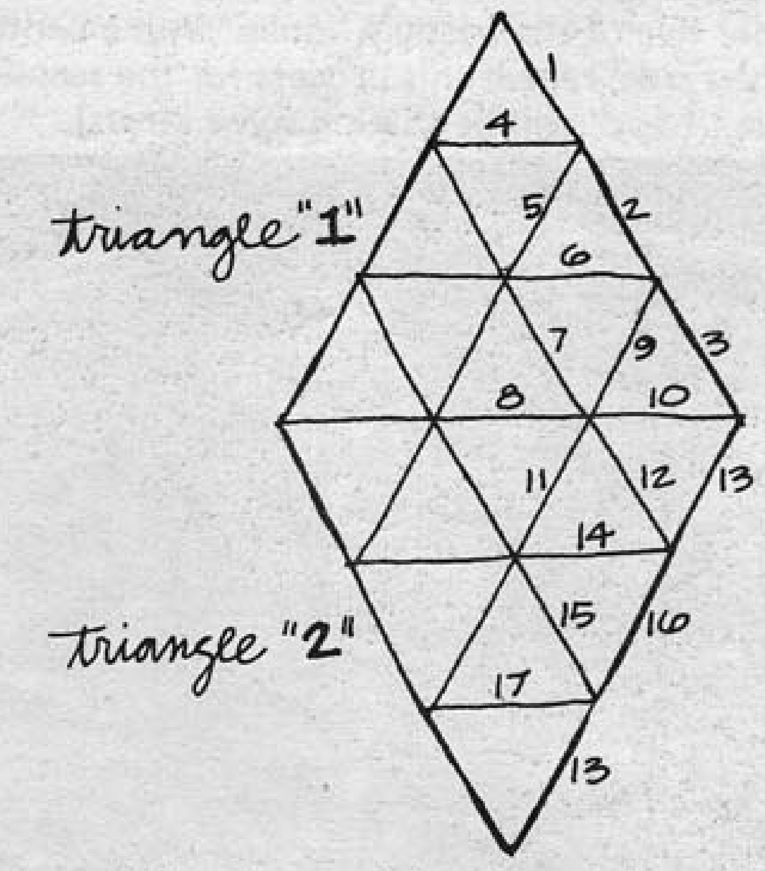
# ELLIPTICAL DOMES



I used the strap and pipe hub method with 2 X 2 redwood struts. It's important to label clearly the different strut lengths with their position, and keep them separate. Make a diagram numbering the different positions and use it to locate the proper struts while you preassemble pents and hexes, and when building the frame. What goes where gets complicated, so spend a lot of time studying your model. I cut 12 different lengths (there are repeats in the tables and some are close enough to round-off) and used four different axial angles. Remember to subtract for hubs and cut your longer struts first so that the leftovers may get used on the shorter struts.

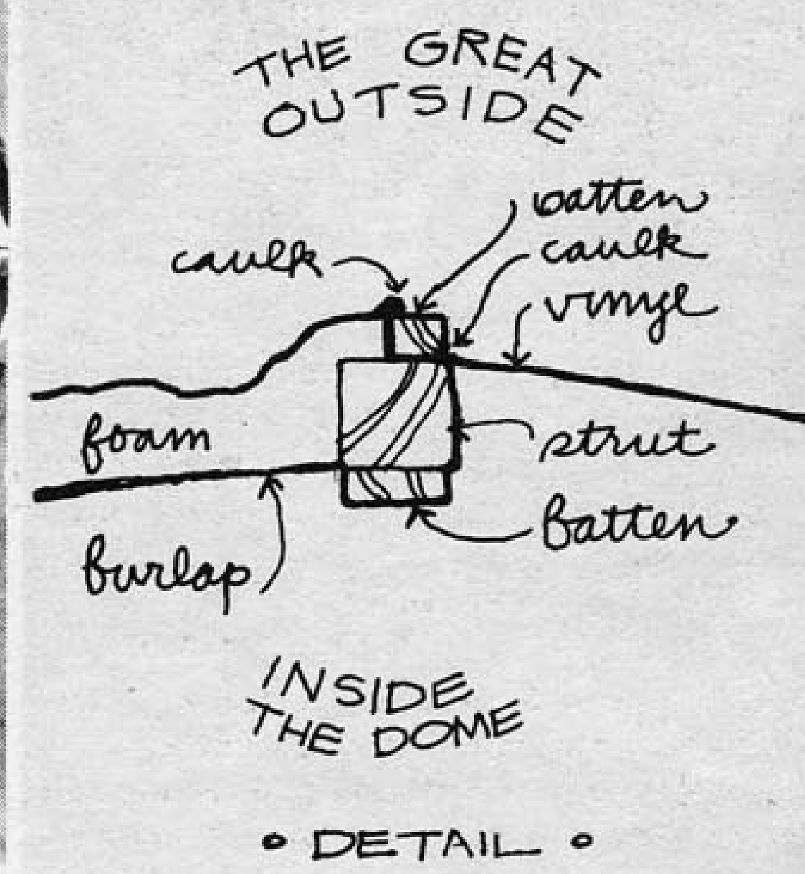
Tables for Egg

| Strut | Number |
|---|---|
| 1 | 5 |
| 2 | 5 |
| 3 | 5 |
| 4 | 5 |
| 5 | 10 |
| 6 | 10 |
| 7 | 10 |
| 8 | 5 |
| 9 | 10 |
| 10 | 10 |
| 11 | 10 |
| 12 | 10 |
| 13 | 10 |
| 14 | 20 |
| 15 | 20 |
| 16 | 10 |
| 17 | 10 |
| Total | 165 |




I put burlap on the inside of the struts and shot the outside of the dome with foam. This method is a lot better than putting the foam on the inside of the structure, because it creates a monolithic rough exterior, and the burlap on the inside is beautiful and easier to live with than the plastic. I put redwood battens on the inside to hold the burlap tight against the struts and because it looks really good. For a plastic building it feels very mellow and fits well in the country.

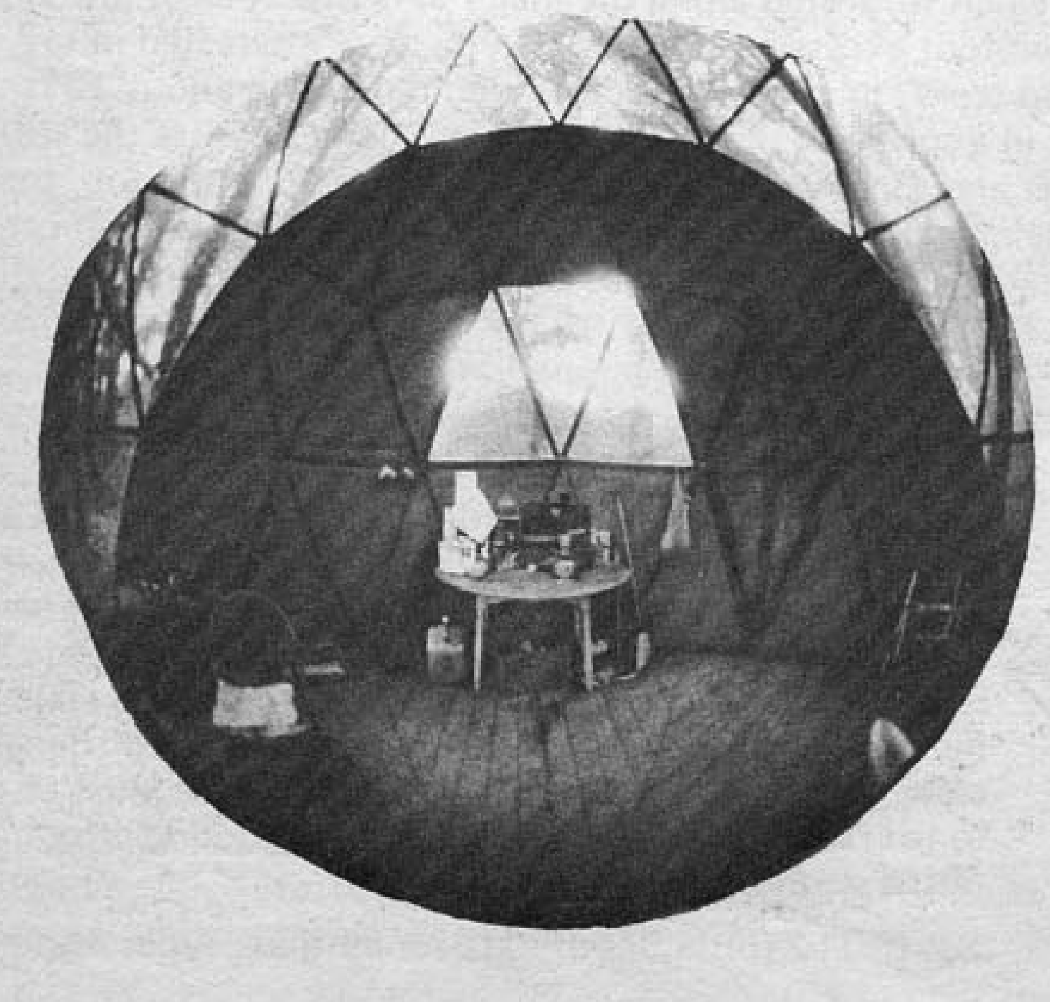
Stretching burlap is a minor craft; always pull with the thread, work a diamond at a time, stretch across diagonals to parallel sides, and play it by ear. You really have an opportunity to try different window patterns if you can afford the burlap.



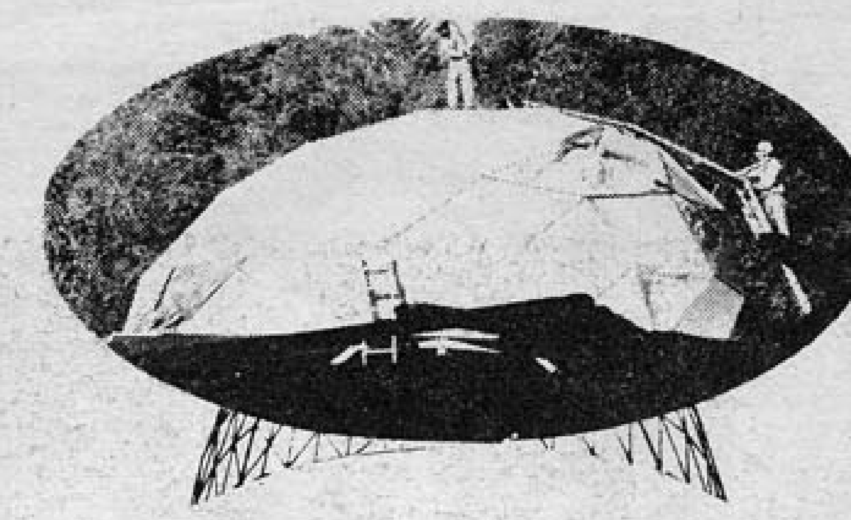

Foam doesn't form a watertight seal with wood so be careful around the windows and floor. It's best to cut off your platform before foaming and foam right over the edge. I put vinyl windows in after foaming(which was a mistake) by cutting the foam back about half an inch on the struts, stapling on the vinyl, putting battens along edges, and caulking both sides of the batten. I used Elastron to protect the foam from ultraviolet deterioration.

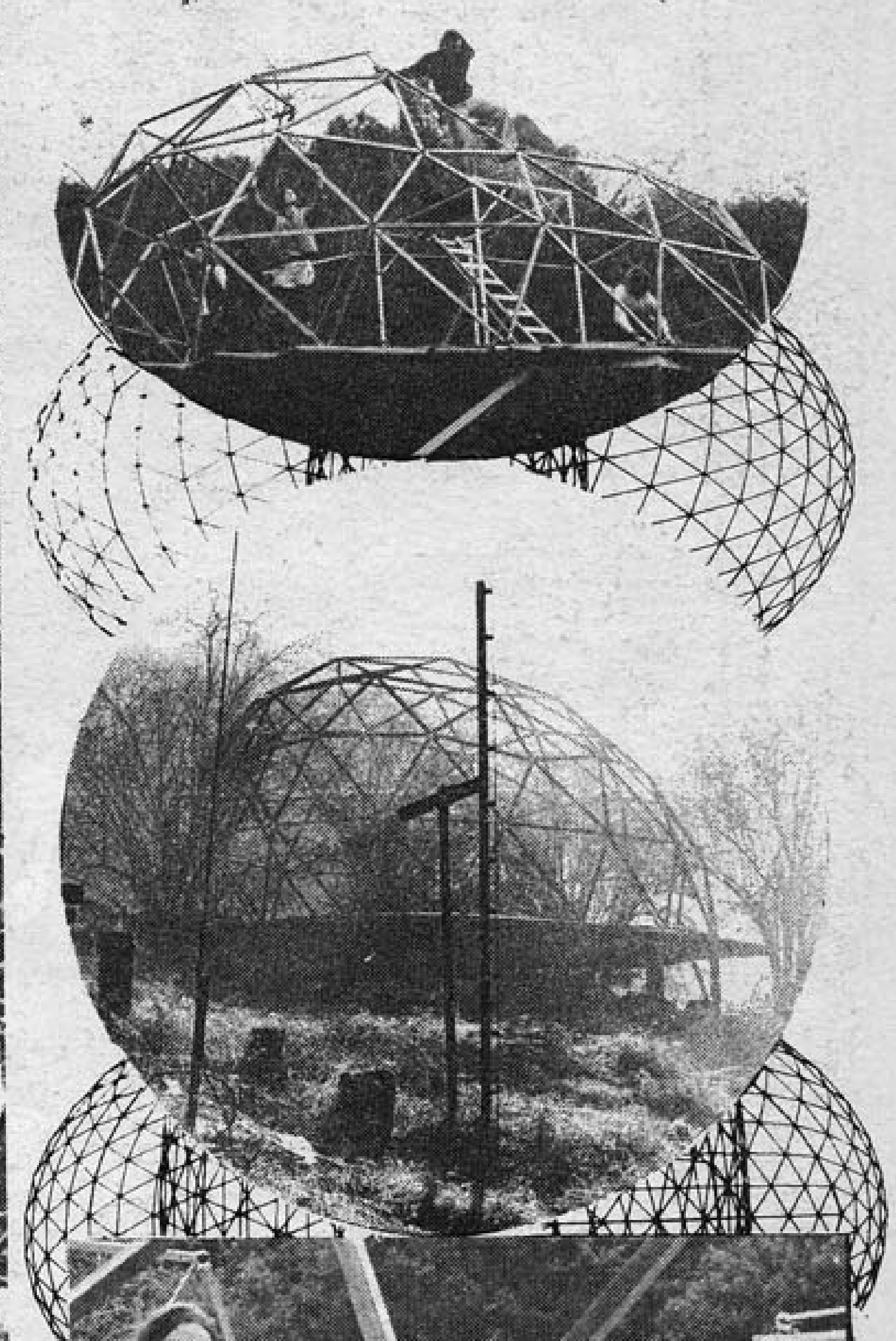
## EGG

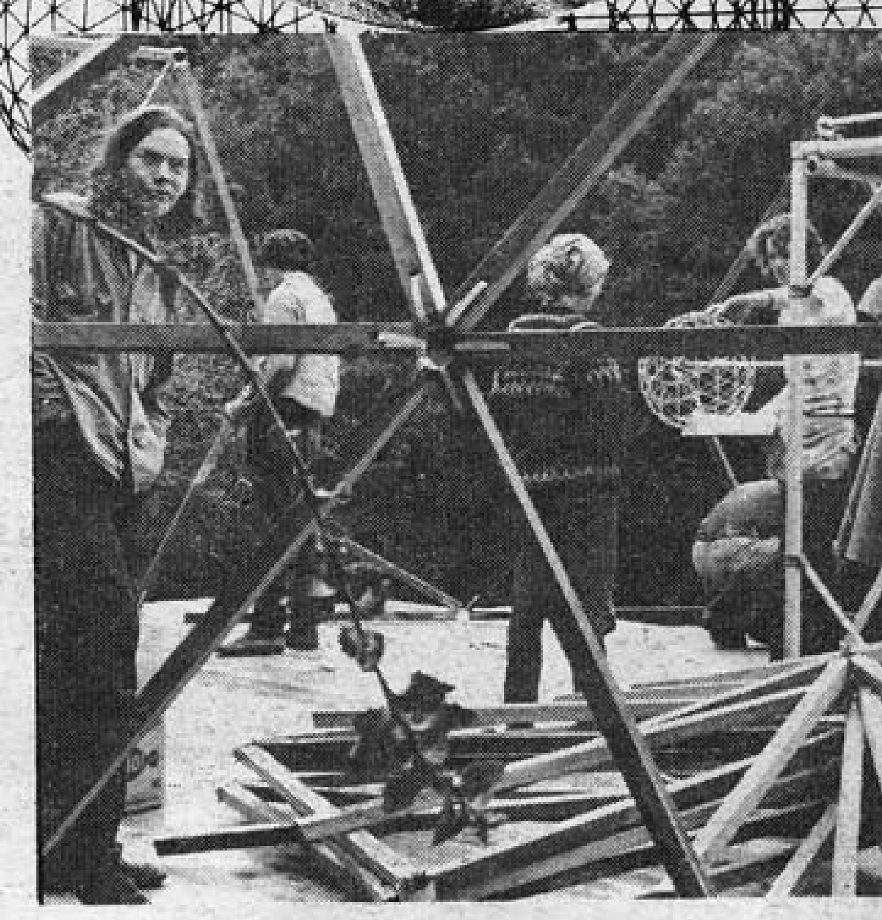
This is a 3-frequency alternate stretched by an expansion factor of 1.618(the golden ratio) and truncated at the 5/8 mark near the minor axis. It has a circular floor and so much head room that people say its like a cathedral. I used foam because it meant i wouldn't have to cut and fit the different triangles, and the resulting monolithic surface would need no caulking.



# ELLIPTICAL DOMES







## ZAPOCHE

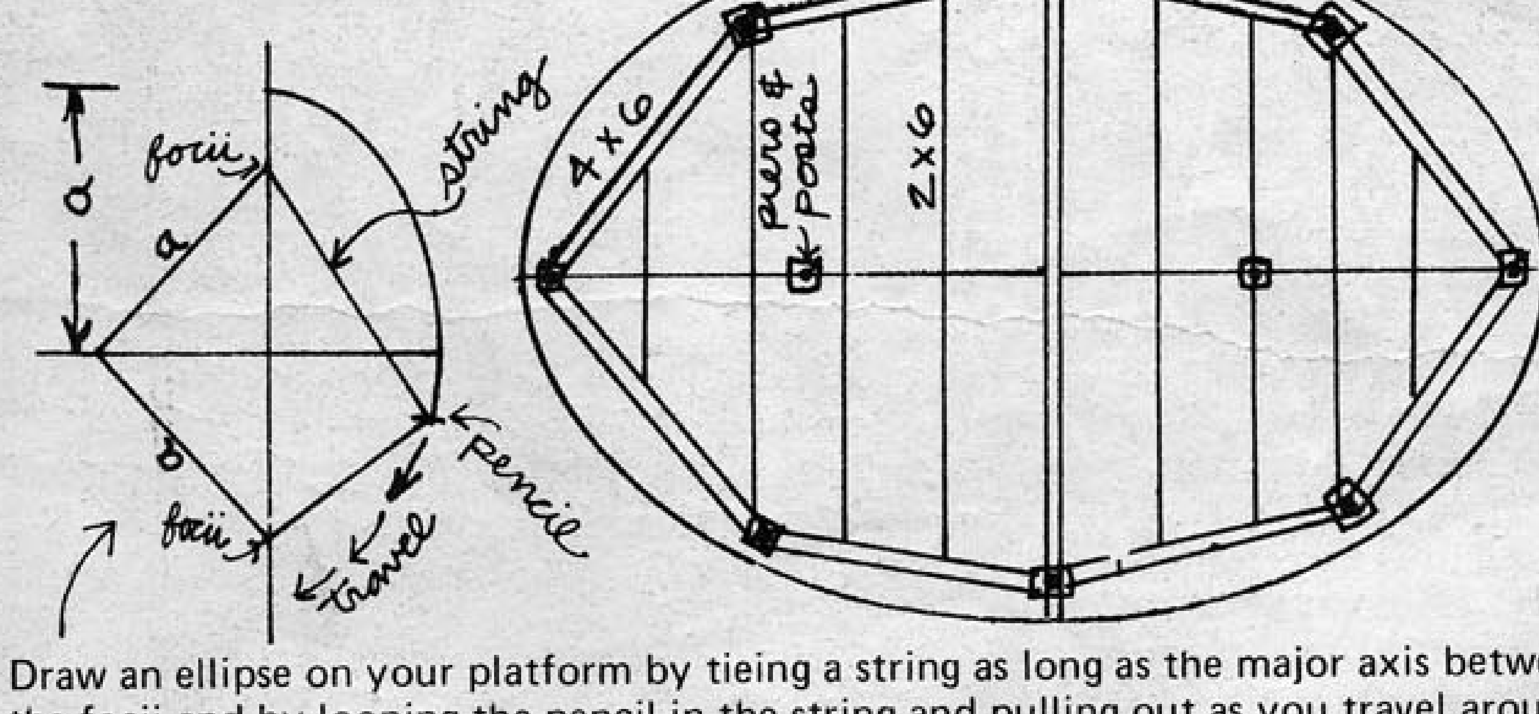
This is really the same structure as the first egg, strap and hub with 2 X 2's, but truncated on a diagonal line(the big window in the other dome is in the position of this truncation). It has a 20 ft radius but is stretched so it has about as much floor space as a 24 ft sphere. The interesting thing about this dome, besides its lunging appearance, is that it has an elliptical floor. The space is not uniform, more symmetries disappear, it is taller at one end than the other, and allows a natural segregation of the space.

The cutting and labeling procedure is the same as the other egg except that there is a different number of each strut type. You've really got to study the model to put this one together because the positions are confusing without the simple symmetries. Here is a table of the number of each strut used; the total number of struts will equal 165 just like a regular 3-frequency alternate:

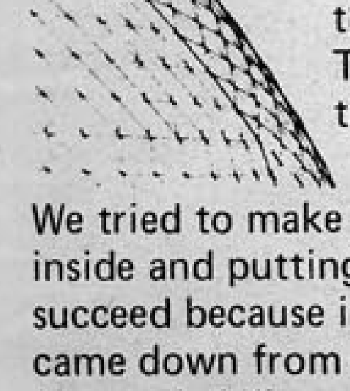
**Tables for Zapoche**

| Strut | Number |
|---|---|
| 1 | 5 |
| 2 | 7 |
| 3 | 5 |
| 4 | 6 |
| 5 | 14 |
| 6 | 14 |
| 7 | 14 |
| 8 | 7 |
| 9 | 12 |
| 10 | 10 |
| 11 | 14 |
| 12 | 12 |
| 13 | 10 |
| 14 | 12 |
| 15 | 12 |
| 16 | 6 |
| 17 | 5 |
| Total | 165 |

Making an elliptical floor in such a way that none of the beams are outside the perimeter is hard. The minor axis of the ellipse is the diameter of the dome (20 ft) and the major axis is about 2 ft less than the expansion factor times the diameter, because the diagonal slice of the dome is not quite as long as the zenith to zenith slice. I just drew it on graph paper and approximated the lengths. The perimeter 4 X 6 beams were equal in length and the posts not on the major or minor axis were located by strings. Mitering angles were measured once the posts were set with a protractor and strings. Here's how we framed it:

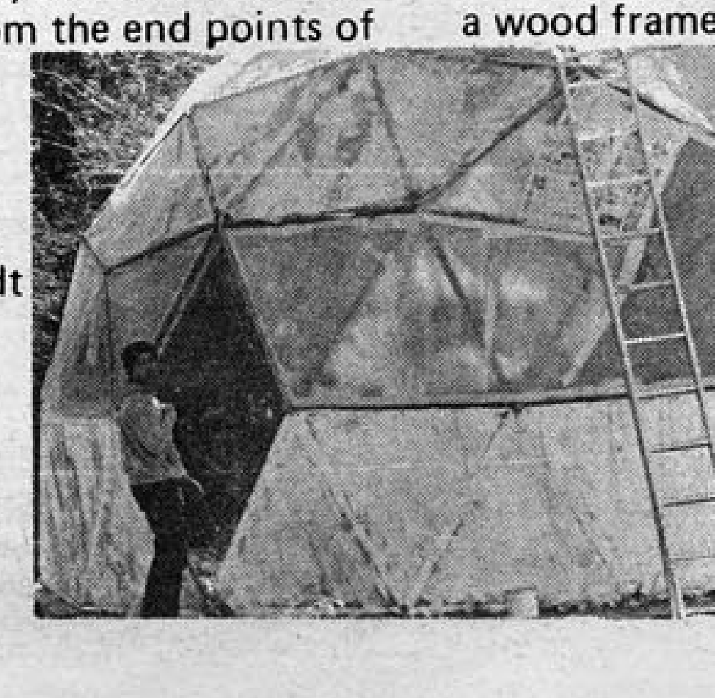



Draw an ellipse on your platform by tieing a string as long as the major axis between the focii and by looping the pencil in the string and pulling out as you travel around. The focii are located by being half the major axis' length away from the end points of the minor axis, and on the major axis.



We tried to make this one have a regular smooth exterior surface by shooting the inside and putting a 1/8" covering of high density foam on the outside. We didn't succeed because it's against the nature of foam to be even and exact. Alan Schmidt came down from Ananda and said they were using fiberglass screen to shoot on. It sounded like a good idea because it meant no stretching but it turned out to be the biggest mistake possible; the foam, i was later told, went right through the screen. So we spent about a week painting the screen to fill the holes, it was a total mess. When it was finally shot the screen was so fucked up that we had to put a coat of two pound foam on the outside before the high density.

*Don't use screen.*



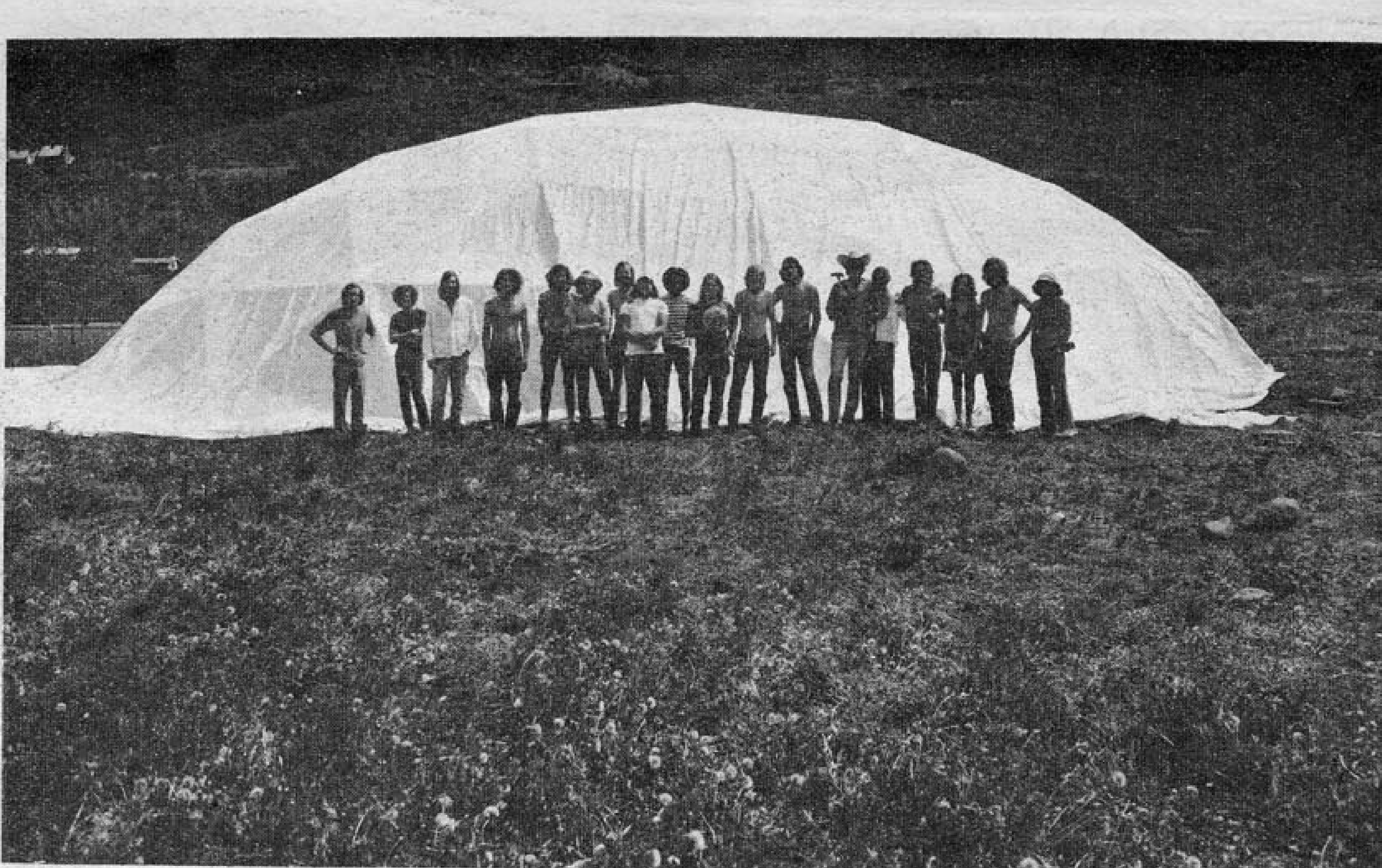
We had the windows ready for the foaming this time and masked. Dick foamed right over the battens and saved us the trouble of cutting a place for the windows and a little caulking (it was also easier to put the windows on before because you could climb on a frame). We shot the foam over the edge of the platform to prevent any seepage there. On the whole this method of shooting the foam on the inside and having the material on the outside of the struts just doesn't look or feel as good as shooting on the outside.

## CONCLUSION

In general the building techniques used for regular domes can be used for elliptical domes. The exception is that the methods of building portable domes require the use of dihedral and face angles, which are so varied in the nonspherical structures that it would be very time consuming, if not impossible to cut the components. With a permanent frame there are several general methods of skinning it: with solid materials like wood or metal, with fabric membranes like vinyl or cloth, or with liquid materials which harden into monolithic shells like foam or ferro cement. The first method would involve making more templates (there are 14 different size triangles in the egg dome) for cutting than the modular sphere, and would take, say, an extra day of work. But this type of construction always has the problem of sealing all the seams. I don't know too much about tent type construction (see p. 48) but i guess it would be a way of building a portable elliptical with, say tube frame and skin hanging inside. The monolithic methods seem most attractive for permanent structures. The foam works and if you consider that it acts as a structural, waterproofing, and insulating material, it's not that expensive. It's a very quick and easy way to put up a place. The ferro cement seems like a really exciting technique because it would be cheap, easy to build by stapling expanded metal onto a wood frame, and extremely strong.

## COMING SOON:

Fig. 71. Three views of a foraminiferal shell (*Trochamma inflata*). After Brady. From P. Grassé, *Traité de Zoologie* (Paris: Masson et Cie).



**70' diameter elliptical tent dome built in Aspen, Colorado.**

# ASPEN DOME

Chip Chappell

The following is an account of the construction of a 70' diameter elliptical "zafu" dome for the International Design Conference at Aspen, Colorado.

On June 2, 1971, Jack Roberts, president of the IDCA, called and asked me whether or not I could provide provisional shelter for the conference beginning June 20 in the event that a tent from Osaka 70 could not be obtained. I telephoned Bob Easton and we discussed what could be done. He, in turn, phoned Lloyd Kahn, with whom he had just written *Domebook 2*, and Peter Calthorpe, whose new geodesic forms based on elliptical spheres of revolution had been published in the *Domebook*. In addition to the feasibility of a dome, I checked into the possibilities of an inflatable swimming pool cover in Aspen, tents from Abbey Rents in Denver and LA, and scaffolding. On June 3, Jack cancelled the tent from Japan and told us to go ahead.

*worlds first zafu*

The original plan seemed to call for a 50' dome which we decided would be more interesting if it were elliptical, since one of the "zafu" type had not been built before. However, we realized 2 days later that the space requirements needed by the Conference necessitated a dome of 4000 sq. ft. or an approximately 70' dia. dome. This seemed impossible to do given the seventeen days we had to complete it. That is, to everyone except Bob. Bob felt the romance and excitement of trying to pull off the project against the cautions of several architects and lack of engineering data on this new form. Besides, we realized that the elliptical "zafu" was our only practical choice, the highest point of the structure being only 18 feet high, whereas a spherical dome would have had a ceiling around 30' high, enclosing unnecessary volume and requiring excessive scaffolding. Structural considerations were concerned with the axial angles of 4.5 degrees near the top, that these relatively flat angles, combined with 11 foot long struts would cause the dome to "pop-in," but with the full backing of program director Dick Farson, the Graham Foundation and Jack, we began.

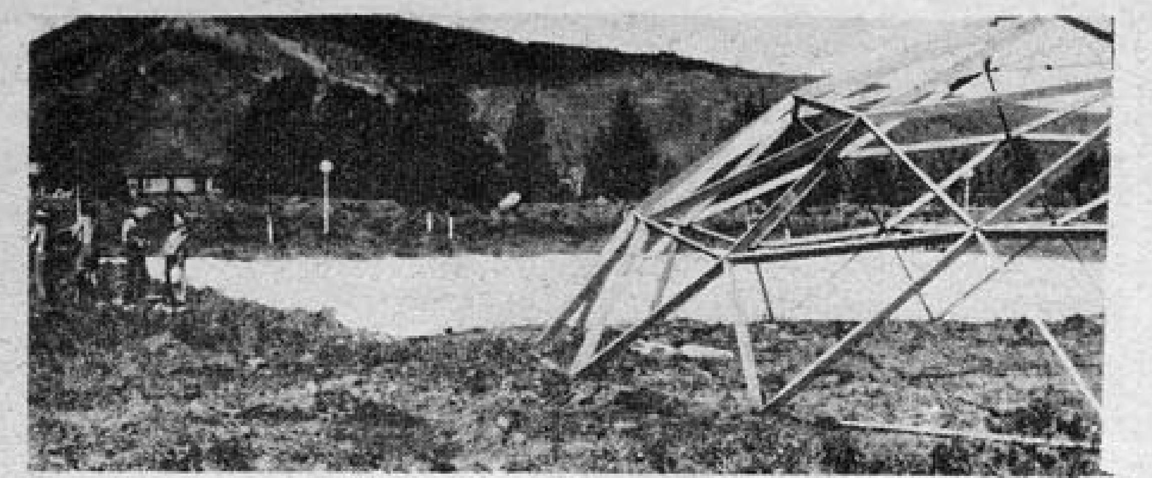
Peter phoned us the chord factors for a 4V 3/8 alternate elliptical. Bob and I computed strut lengths, and organized material orders and a work schedule. All of our work prior to Aspen was complicated by the facts that: Bob and I had other full time commitments, Peter was in Washington DC, that I had to commute from Santa Barbara to LA and back each day, and that our building crew in Aspen has never worked together before, and couldn't start to put it up until June 14.

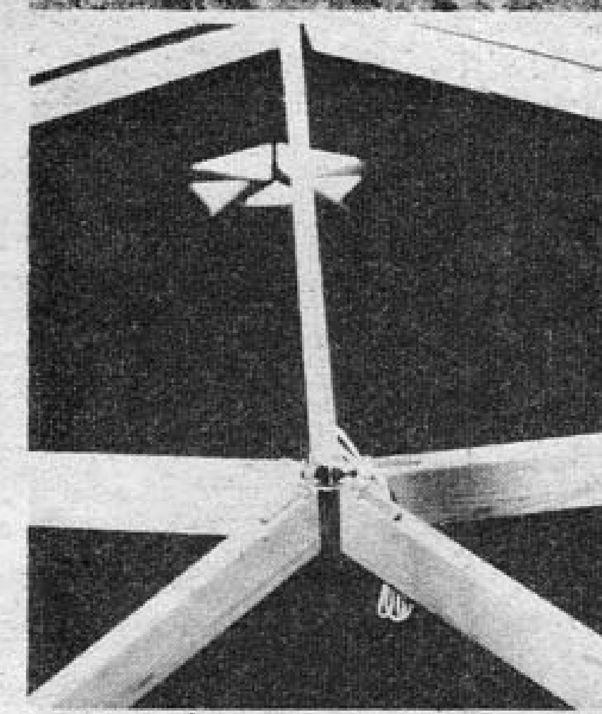

The struts were 2 x 10 construction grade douglas fir, ripped down to 2 x 5". All the wood cost us $310, construction grade is adequate structurally if the knots are tight. The 23 different struts length were cut with a radial arm saw and ¾" holes drilled 3" from each end. There were a total of 190 struts which were cut and drilled in one day. Simultaneously C.D. Reily Co. was cutting steel pipe into 4" pieces. I picked up 5/8" stainless steel band-it strap and strappers from Zumar Industries, LA. Our first test (June 7) of the hub and strut connection failed. We then used the experience of Jeff Morse (p. 51), and added 1/8" steel plate on the end to prevent the wood from being crushed by the pipe, (we did not cope the ends of the wood). And ¾" steel half round to prevent the strap from compressing the wood at the drilled hole. With these additions the connection was extremely rigid and strong, and gave us a great deal of confidence that the dome would work and that the 4.5 degree axial angles wouldn't "pop-in."

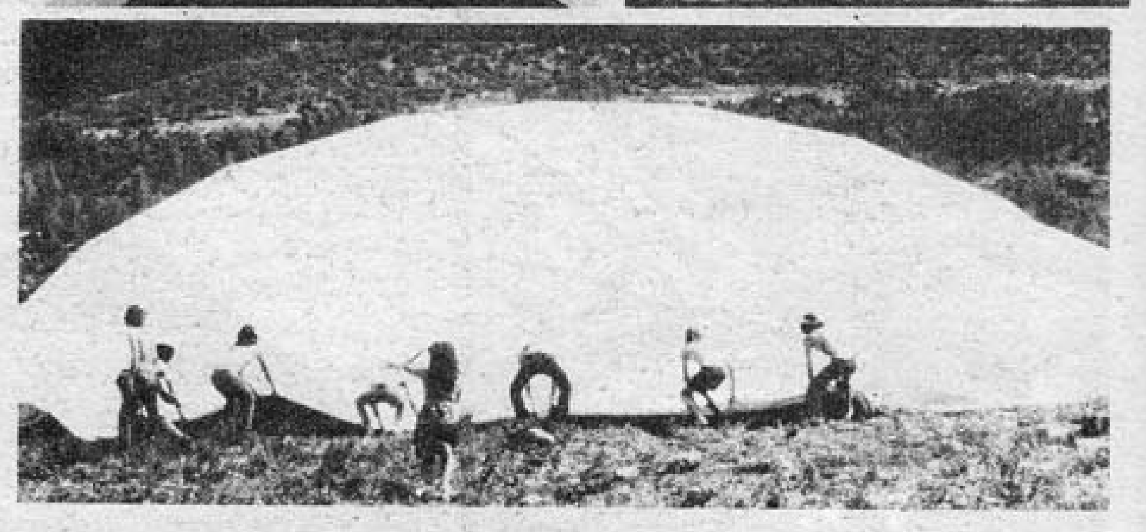
The main problem we were experiencing at this time was the skin. Our job was to provide a dry space in the case of thunderstorms and many people had made sarcastic comments about leaky domes. We hoped first to waterproof a 100' nylon parachute but we couldn't find anyone who could do it. With some hesitancy we turned to canvas. Making a shaped skin was too expensive and time-consuming. So, after shopping around, we selected Canvas

Loft, S.B. to sew an 86' square out of 8 oz. Vinitex canvas. It cost $1019. We attached the canvas to the frame by battening around the bottom and by using nylon guy lines run from the top hole down over the top of the canvas and tied to each pent hub around the lower course. To relieve internal pressure we made a 5' hole at the top hub. The lower course was secured to the ground by burying screw-in type augers from the Sears Catalog and bolting thru the eye in the auger and the ground hub.

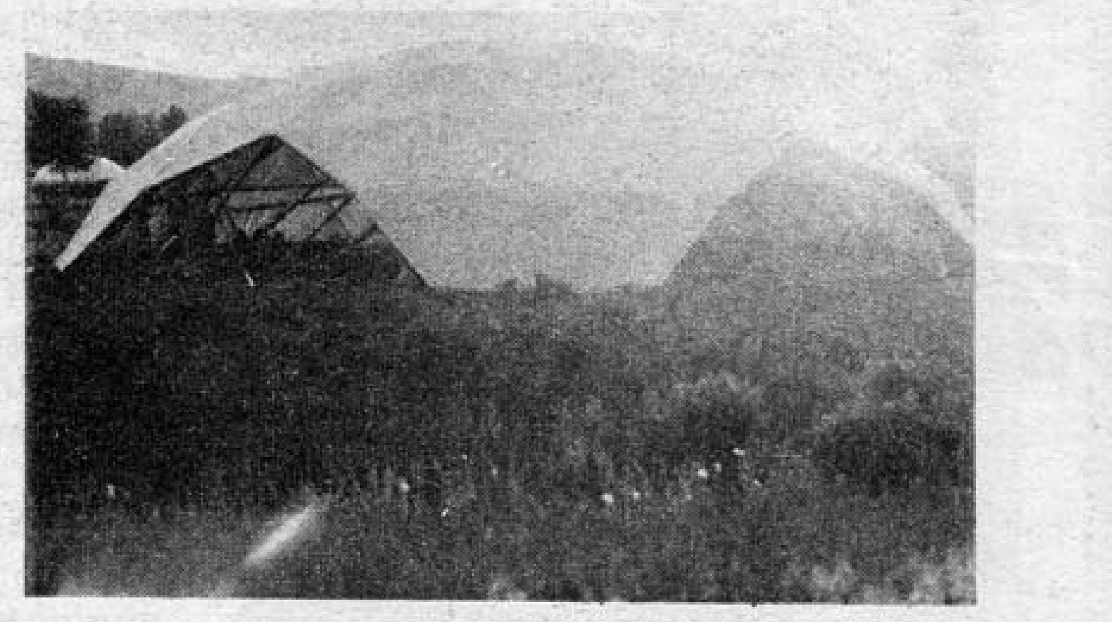
On Saturday June 12, Daniel Zolotow, Suzanne West and I left Santa Barbara with a 12' U-Haul truck loaded with all the dome parts and tools for the job, and arrived in Aspen 30 hours later. Bob arrived Monday and Peter, with Mark Efross, Peter Lustig and Jonathan Kanter arrived Tuesday. We selected a site that was fairly flat and laid out the bottom course of the dome that afternoon. On Wednesday, we erected most of the frame and on Thursday, completed it. The structure was self-supporting all the way.

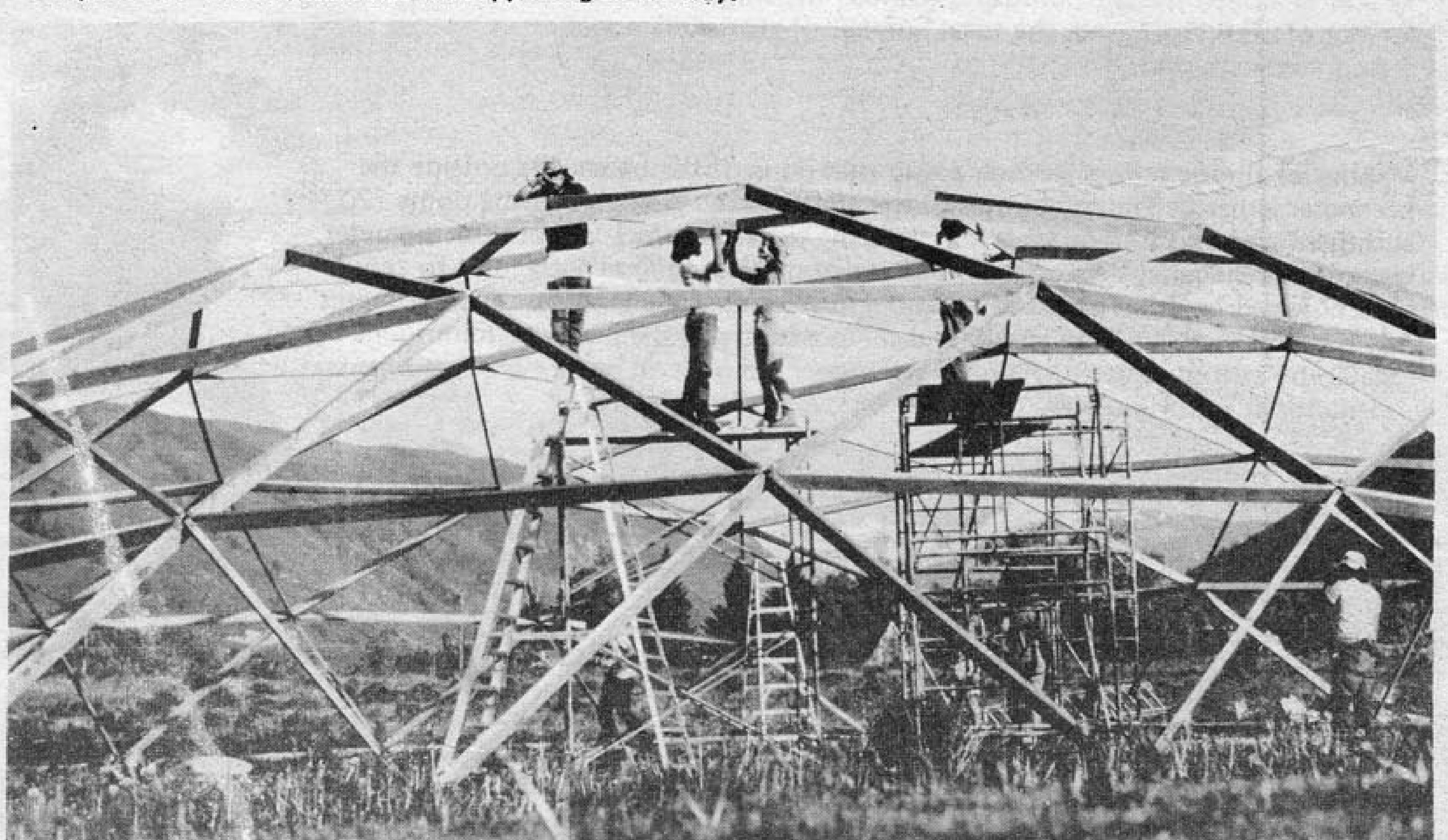




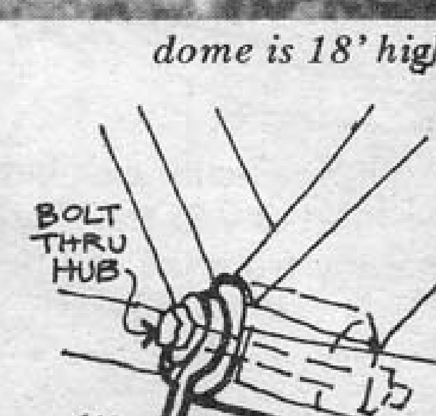


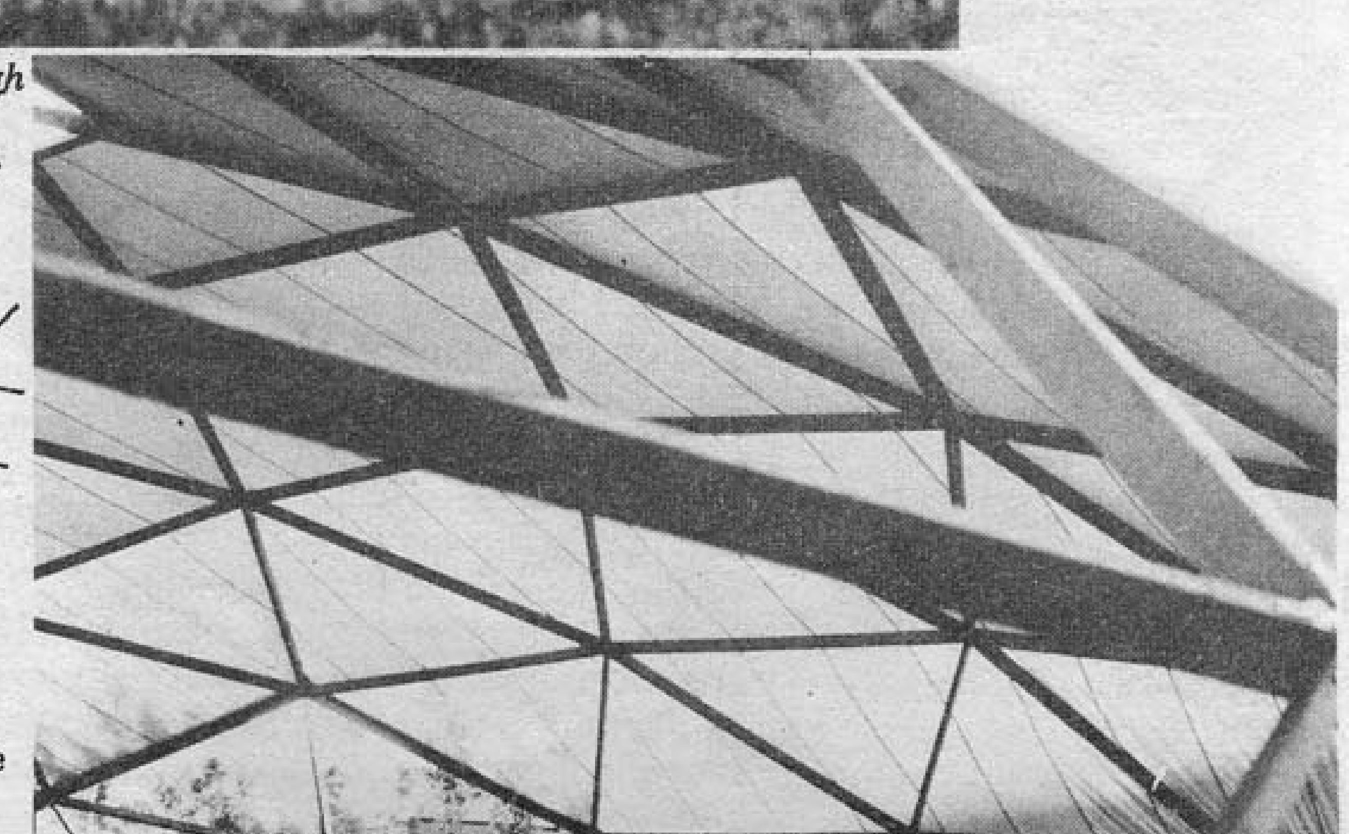
On Saturday we pulled the canvas onto the frame. The natural color of the canvas created a warm, mellow light inside. It was the right material for the skin. In addition, the relative flatness of the elliptical dome at its center meant that the canvas didn't bag and wrinkle as we feared it might. In fact, the canvas fitted almost perfectly and only slight tucks were taken in around the bottom. Triangular openings were cut around 3 of the bottom pentagons and one pentagonal opening at the top. When these were battened down the dome was completed Sat. June 19. The Conference opened the next day.



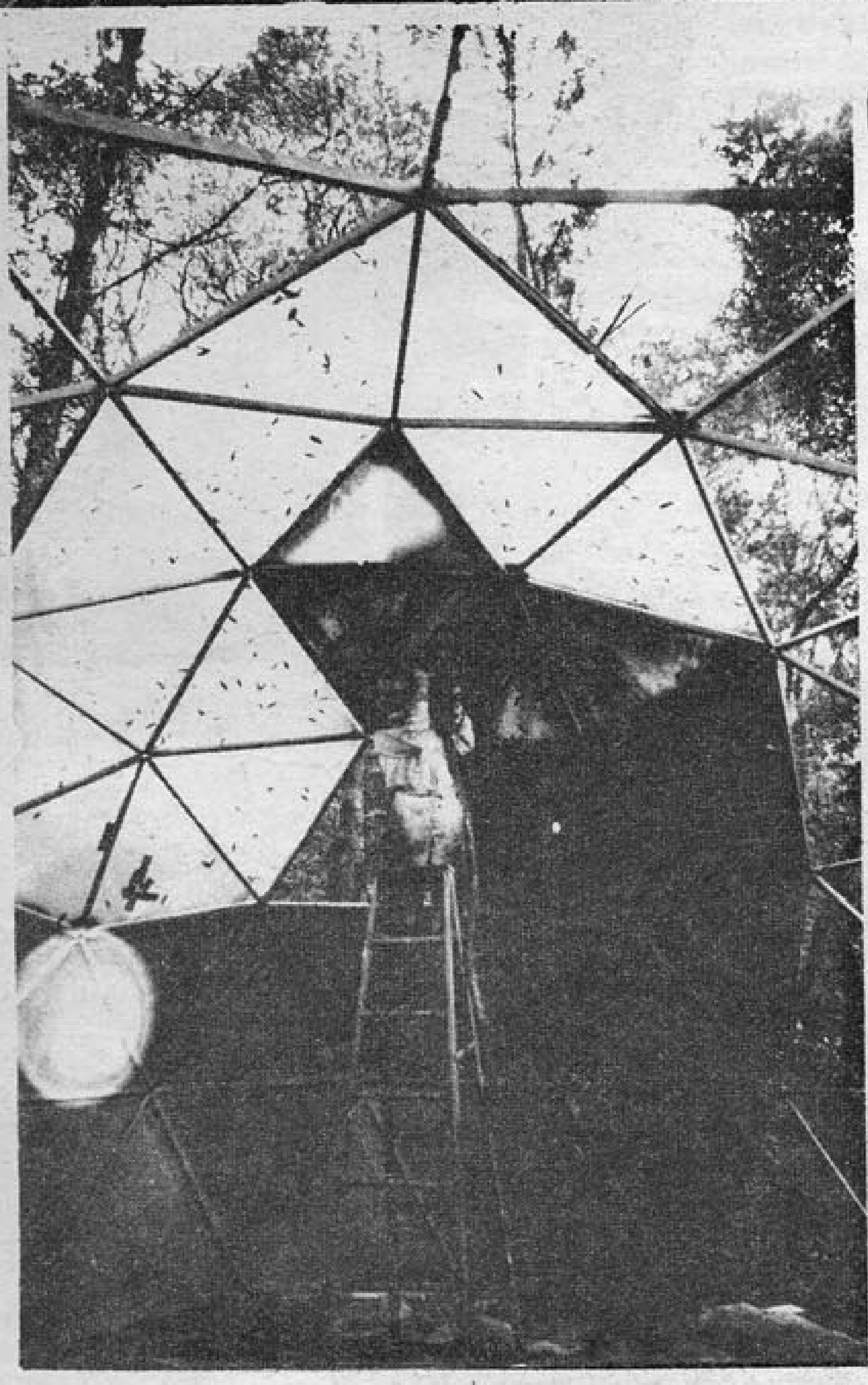


*dome is 18' high*

Construction was reasonably effortless. Friday (June 18) was like a day off. The ground was so rocky (The Rocky Mountains are) that we hired a back-hoe to dig the holes for the augers. This took 2 hours.



# MUSLIN-FOAM DOME

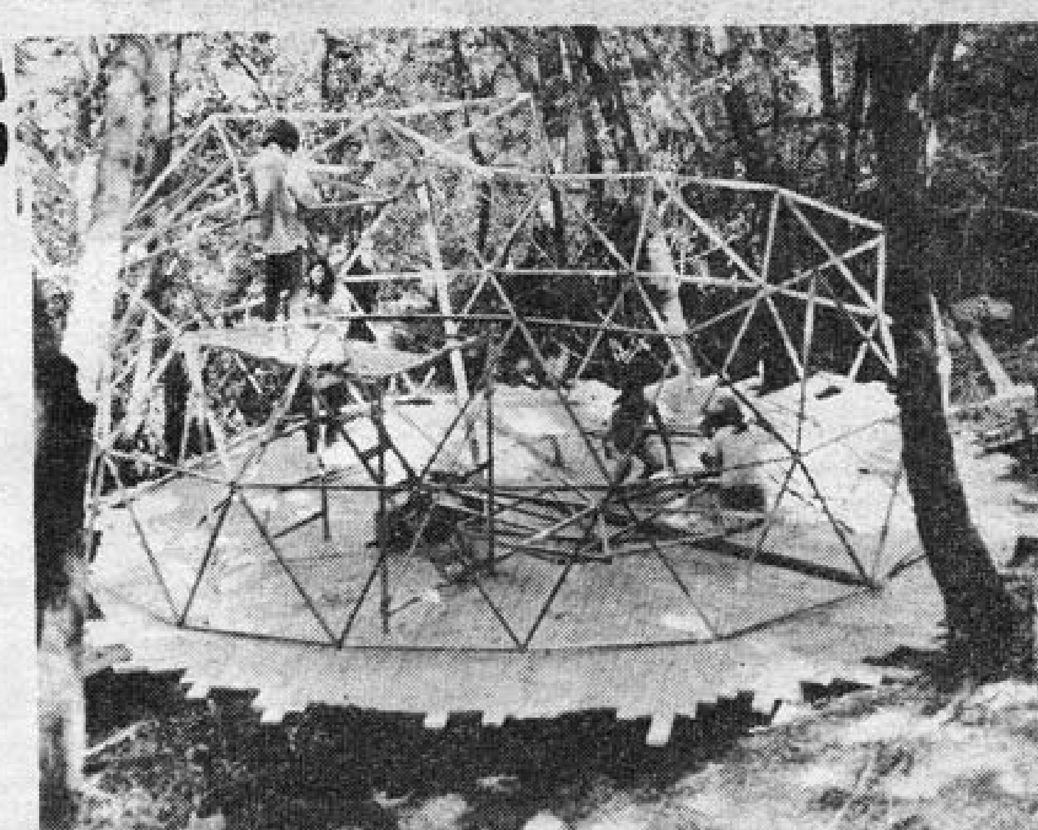
Jonathan Kanter

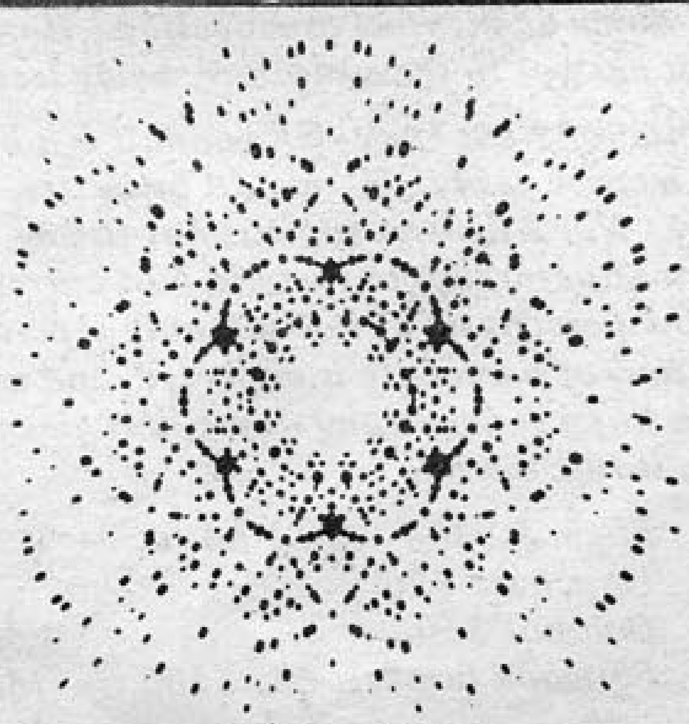
We got the idea to do the foam domes from an article on a foam house in *Life*.

The dome's a 22 ft, 3-frequency with 2 X 4's ripped into thirds for struts. That's too light to climb on unless you step next to the hubs. First I stapled muslin onto the frame. It's about 40 yds of muslin 45" wide. It was thin muslin and getting it on tight and without wrinkles was hard. We resined fiberglass tape over most of the struts to cover the bumps around the staples(from the stress in the muslin), and to cover the open pipe hubs and filled in the holes with caulk later. The dome looked the nicest with just muslin over it, sort of Japanese.

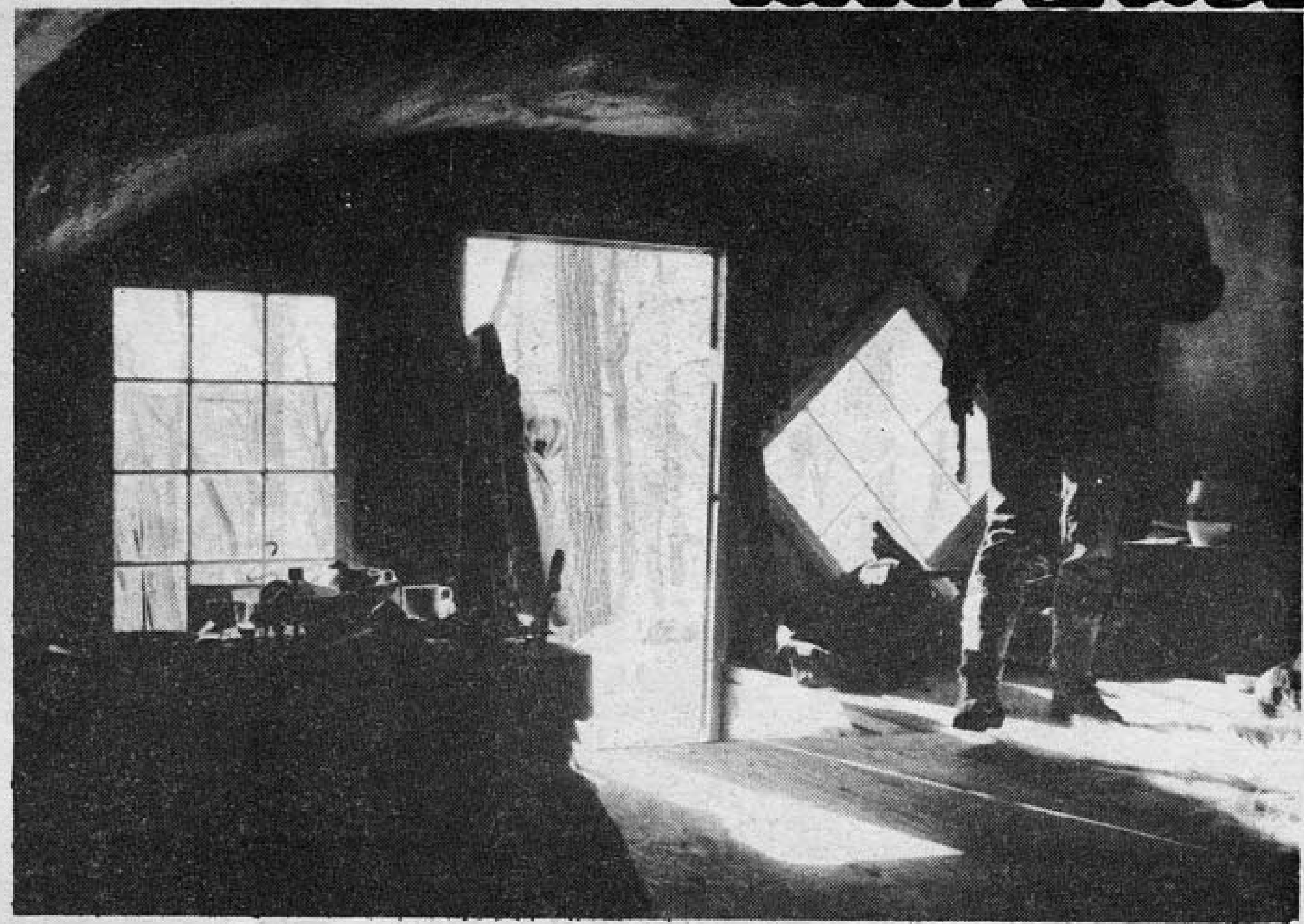
It might be easier to first sew up a whole skin(cutting out for windows later) or sections and attach that to a frame. Instead of coating it first it would be better to hold a piece of plywood as a backing when the foam was being sprayed (so the triangles come out flat). Industrial Covers in S.F. makes a special cloth for spraying foam on that stretches equally in all directions. Instead of having to coat a skin you could just use a long lasting waterproof cloth.

The windows are .040 Lexan. Because it comes in triangular sheets you with have to use halves or waste a triangles worth per sheet. The best way to join halves is to pay someone to ultrasonicly weld them together. We attached the windows by first laying a strip of tape caulk along the struts, putting the window into position and then stapling them into place. You need to use an air staple gun, which you can rent. You could then caulk or tape over the windows. I still don't have the halves on. I cut the windows by putting them into a pile and cutting them with a skilsaw. It was too messy, you should use a plexiglass cutter, you scratch the window and then snap it.

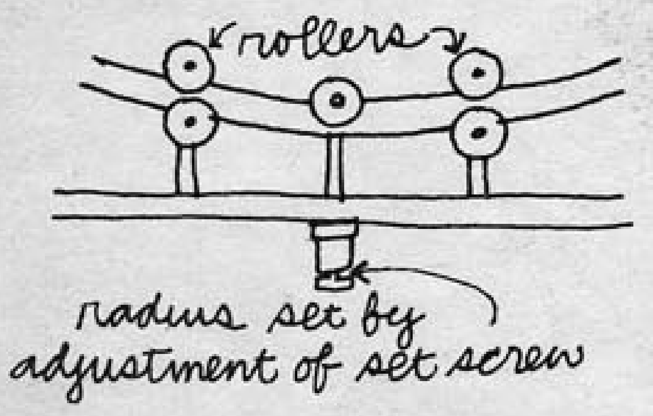


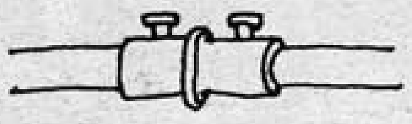


# BACKPACKED FOAM

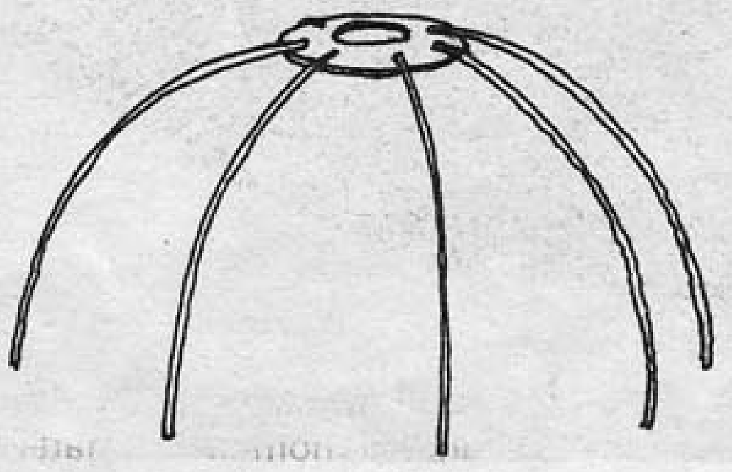


*Shelter was needed. Water-proof—insulated from heat, cold. Used parachutes are cheap. So is conduit. Urethane insulation seals well and is excellent insulation and can be more or less structural. The parachutes are either 24' or 28' diameter measured flat on the ground. Raised up into a hemisphere a dome of about 22 feet is formed which is about 8' high, leaving enough material for an arched doorway. ½" conduit was rolled into a shallow curve using an improvised roller arrangement.*

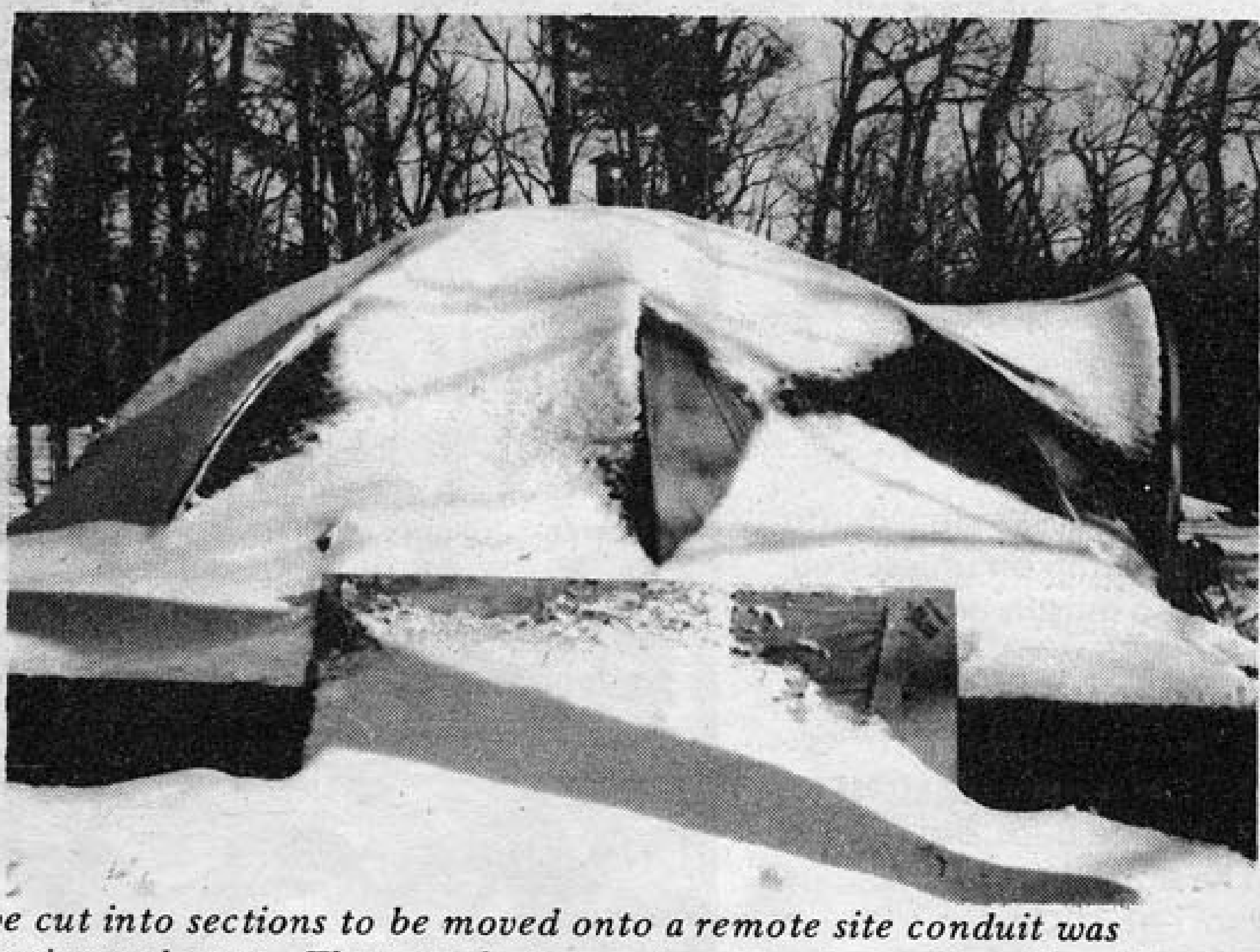


*The curved sections of pipe were joined together using standard screw unions.*

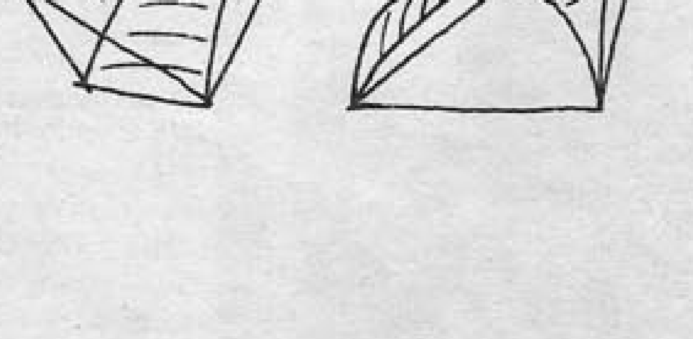


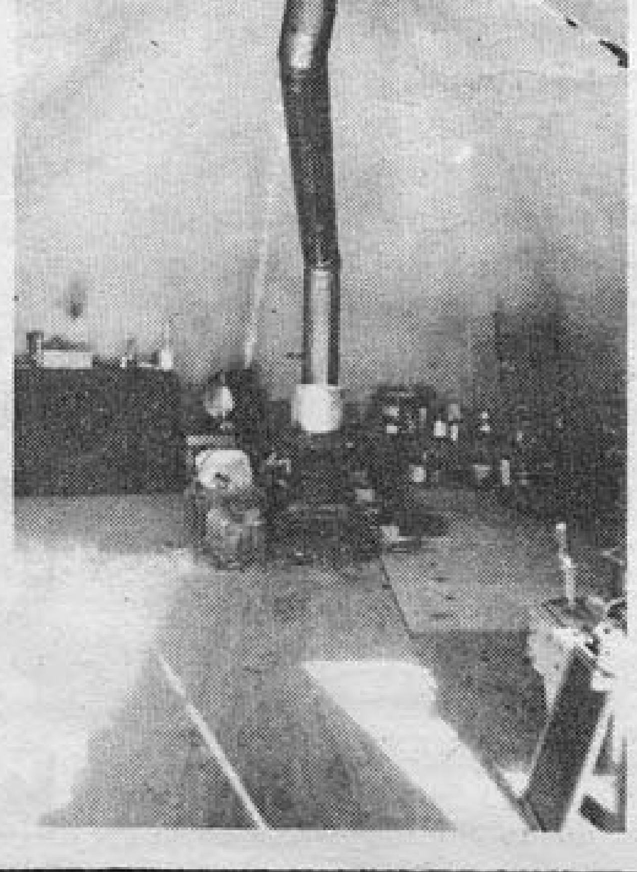
*At the top the ribs were bolted to a plywood ring. The hole in the center is for chimney or summer vent.*



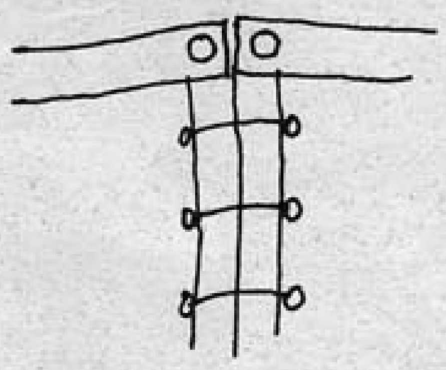
*As this dome had to be cut into sections to be moved onto a remote site conduit was doubled where it was going to be cut. The parachute was drawn taut over the ribs with seams following over conduit. The balance of the parachute was stretched over another arched piece of conduit to form the door area. When all was taut, about 1½" of No. 2 density foam was sprayed from the inside covering the conduit and forming the structure. After it was all sprayed, it was cut into movable sections.*

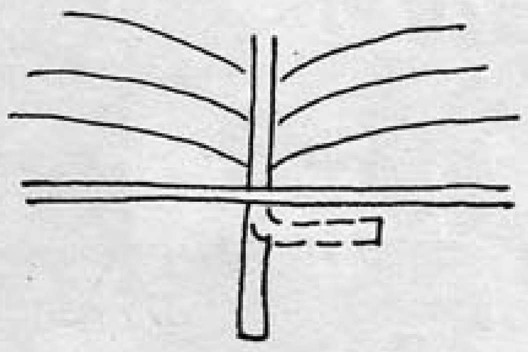
*Each section was triangulated temporarily with furring strips to keep it from flexing too much when it was moved. The sections stacked on top of each other and were moved easily on a flat bed truck to the base of the hill where it had to back packed to the top. The door arch way was far and away the biggest price and had to be triangulated in all directions.*





*After it was carried to the top of the hill(sweat propulsion) it was reassembled on a platform made of plywood on 2 X 6 on stumps and sections of trees. When the sections were re-bolted to the ring of plywood, the edges were stitched together using parachute shroud line and drawn together to seal as closely as possible the remaining gaps...*





*and the entire seams were caulked with silicone rubber caulking compound. When all was re-assembled, holes were bored through the floor and the ends of the conduit lowered into them.. These were bent under the floor to hold the dome down.*

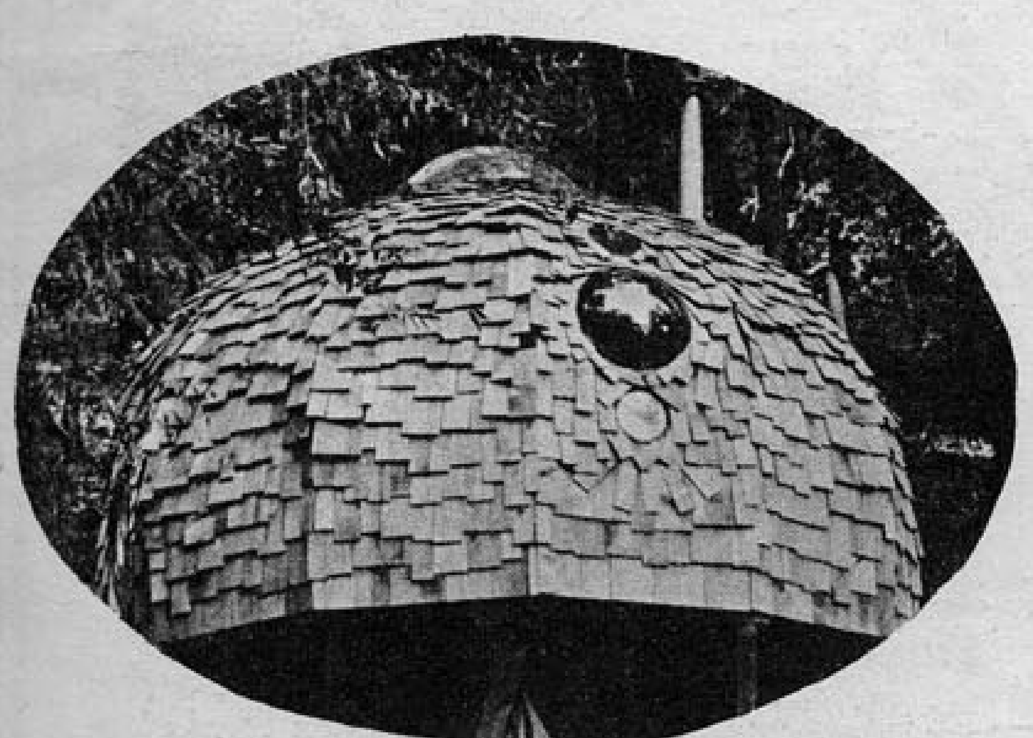
*Styrofoam planks were laid on the wood floor to raise the floor and insulate it, and a second floor added on top of the styrofoam. Wood doors and windows were inset into the foam at the front with steps from ground level up into the dome. Small wood stove over-heated the dome at slightest provocation. How it will be in summer heat remains to be seen, as it has yet to see a summer, being less than a year old.*

*Things learned—Improvements for Next One: ½" conduit is a bit light weight, but was used as it can be rolled into a curve easily. ¾" would be better, but I have no easy way to make the curves necessary. No. 2 density foam is not strong enough. No. 3 or 4 would be a vast improvement structurally, but would cost correspondingly more. The foam didn't adhere well to the parachute, but would only separate if pulled. Some sort of ultra-violet deterioration of parachute is expected, and a coat of protection paint may be necessary. It is not a super strong dome, but given the need for a dwelling between a tent and a house, it fills the bill.*

*Costs: Foam $2-300 @30¢ bd ft*
*Parachute $20*
*Conduit $50*
*Plywood lumber, etc. $100*
*Overall about $500*

*John T. Welles*
*Yreka, California*

# the pod



Martin Bartlett

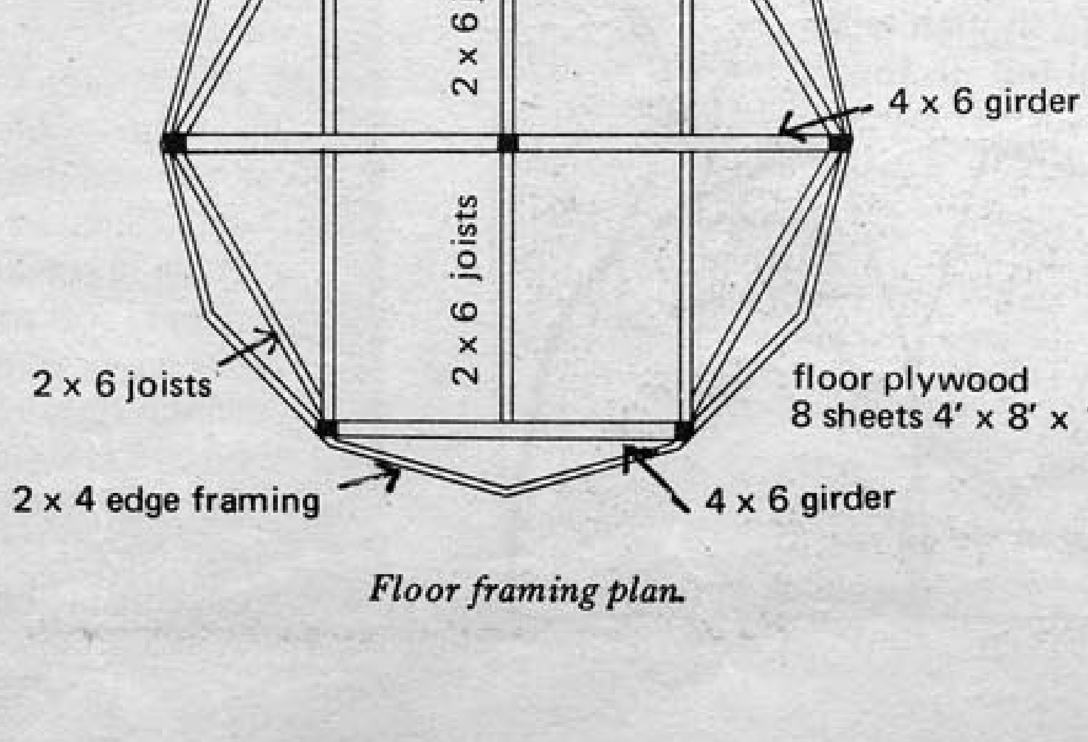
The pod is a dome built out of sheets of fairly thin plywood utilizing the bendy qualities of the material. (Not geodesic) It is very light and economical of material, and should be quite easy to build if you are prepared to cope with the rather unusual problems such a structure presents. It was designed by Bob McElroy and Paul Wingate, and I built mine with no more in the way of plans than some advice from Lloyd who had seen one.

Long pieces of plywood are used. Standard width is 4 feet, and lengths of ten or twelve feet are obtainable in marine grade or occasionally in ordinary exterior grade if you do a lot of phoning around. You are going to have a polygonal floor plan with each side four feet wide. You will need as many plywood panels as there are sides. Needless to say, the size of the structure depends on the number of sides; I used twelve sheets of 1/4" plywood, each sheet 12' long. This gave a dome 15' 5 1/2" in diameter, with a height of about 9 feet. It is a roomy and pleasant space for one or possibly two people. Larger or smaller pods can be built by using fewer or more panels. The formula for working out the diameter of the dome from a given number of 4' sides is

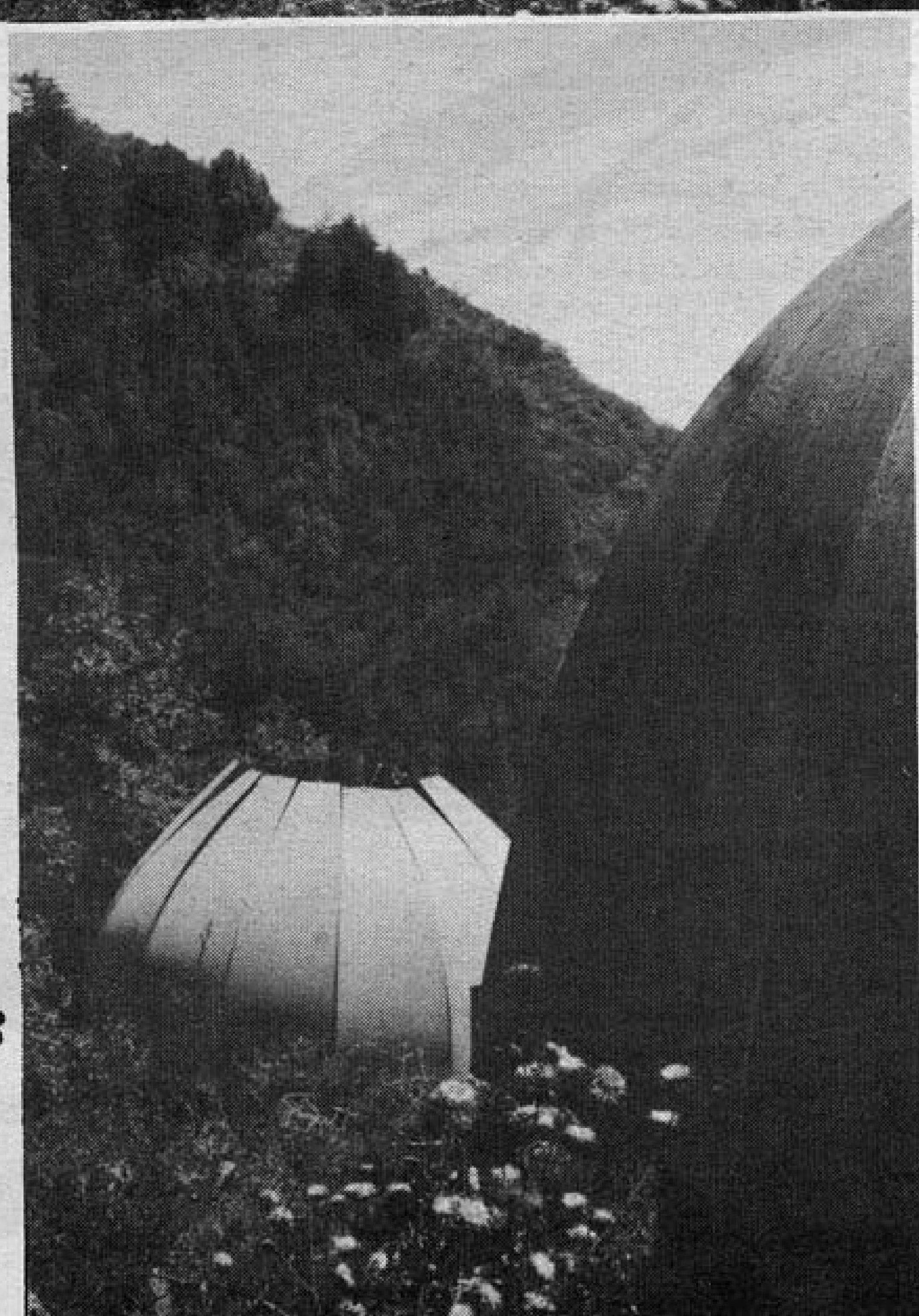
$$D = \frac{4}{\sin \frac{1}{2}\theta}, \quad \text{where } \theta = \frac{360}{\text{no. of panels.}}$$

As opposed to geodesics, in which the larger the better, pods seem best suited to sizes up to about 20 feet in diameter. To achieve a larger space one would need very long sheets of plywood in order to achieve a decent ceiling height within.

Having decided on the size of the structure it is best to build a platform that exact size. Then the plywood can be nailed to the edge of the platform and the rain has no chance of infiltrating itself between the bottom of the sides and the platform. The platform was built in the same manner as those for the geodesic domes with the exception that a strong edge of 2 x 4's was provided beneath the plywood for the skin to nail to. This frame was nailed to the girders and joists which were cut off at the proper angle, and also nailed to the plywood deck. A hole for a trapdoor was left in the platform.




*Floor framing plan.*



## McElroy's pods

## Abalone Creek

### details

*This dome was built on a platform erected from a steep mountainside out into a Bay tree. A sliding glass wall opens the rear of the dome onto a redwood deck which cantilevers out through the tree. Visitors often think that as the tree grows the entire structure will tip but of course trees grow taller from the ends of their branches.*

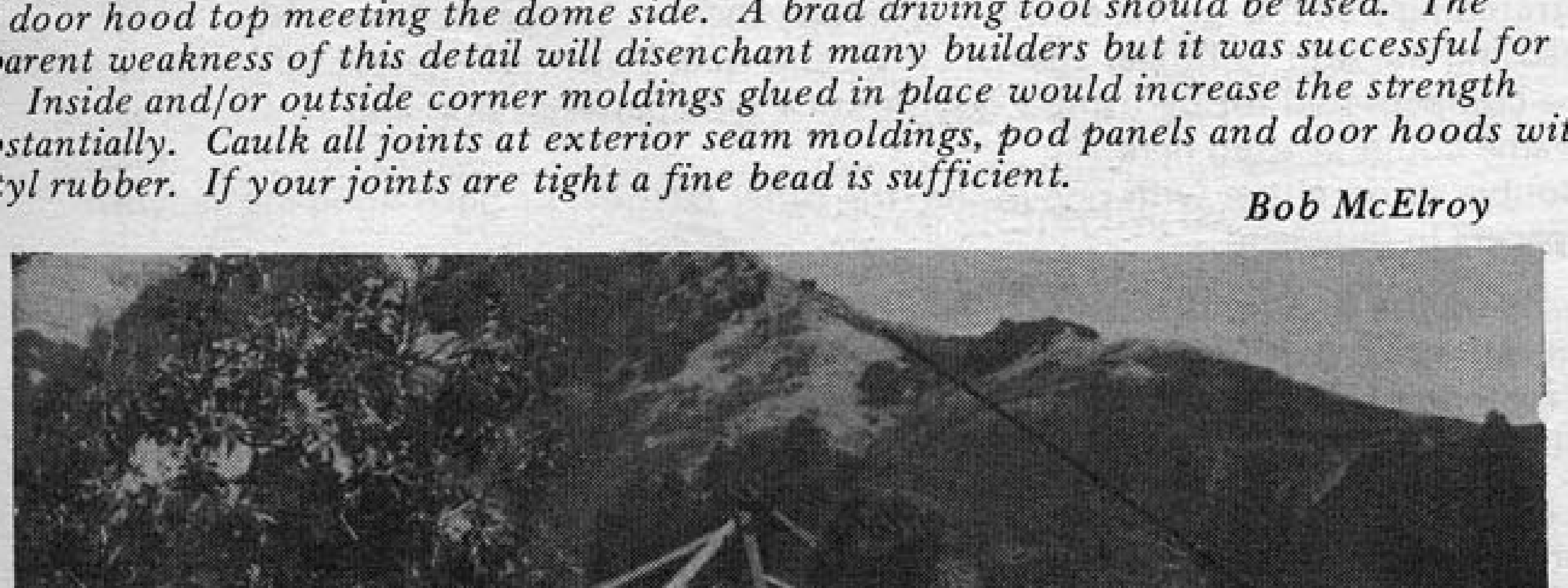
*Fifteen 12' sheets of ¼" fir plywood were used for the pod. Martin Bartlett's pod dome instructions on the preceding pages spell out in detail the necessary construction steps. An improved seam detail was developed for this dome using inside and outside moldings which clamp the panel joints in a secure waterproof grip. The panel joint angle flattens slightly from bottom to top so the angle of the inner surfaces of the sandwich moldings must be a compromise. In addition to bolts, panel adhesive holds the moldings in place and fills the small gap where the molding and panel surfaces don't coincide(see detail).*

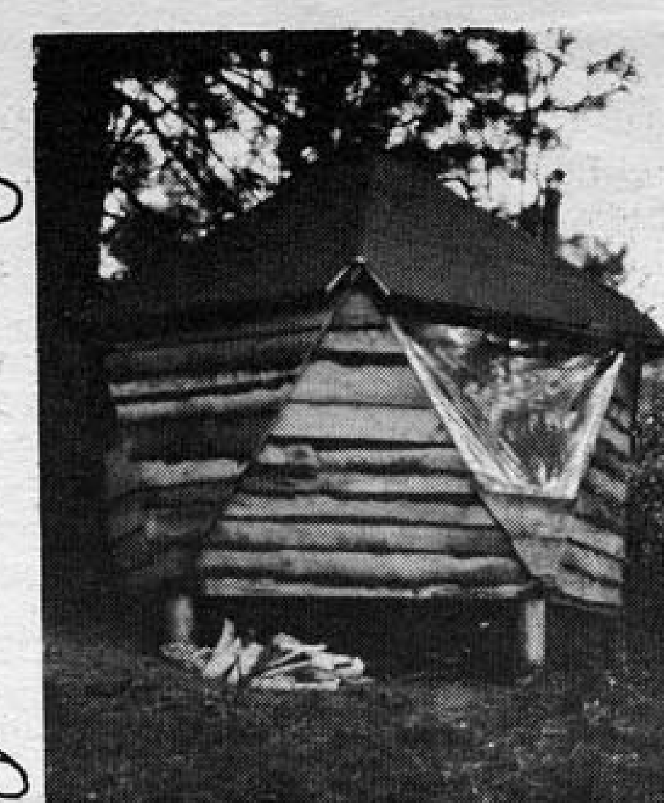
*After the panels were bent into position a 7' diameter skylight opening was left on top. The inside seam moldings were cut off at the skylight edge but the exterior moldings ran on up and met. At this intersection the moldings were mitered and joined.*

*3/8" by 3/4" wood strips were ripped, ends mitered and fastened with brads and adhesive to run down the center line of the top of each of the fifteen exterior seam moldings to a point 6" past the edge of the skylight opening. There were now fifteen triangular openings which were glazed with window glass layed in butyl rubber caulking, and held down by glazing points and beads of caulking. The glass lapped onto the top of the plywood about 6" to shed rain. An 80 mph winter storm worked under this glass overhang and peeled off three lites, so 3/4 by 3/8 wood strips should be used as stops to hold the glass down(see detail). Make sure the glass is blocked from sliding down from the peak since a small slippage could result in the glass triangle dropping into the dome point first.*

*The 2' 6" by 6' 0" entry door and 8' sliding glass wall were installed in ¼" plywood hoods which fastened to the edges of cut outs in the dome sides with brad and mastic secured butt joints. A ledger strip is needed to reinforce the inside of the intersection of the door hood top meeting the dome side. A brad driving tool should be used. The apparent weakness of this detail will disenchant many builders but it was successful for me. Inside and/or outside corner moldings glued in place would increase the strength substantially. Caulk all joints at exterior seam moldings, pod panels and door hoods with butyl rubber. If your joints are tight a fine bead is sufficient.*

Bob McElroy





Icosa Cabins at Ananda

# TENT

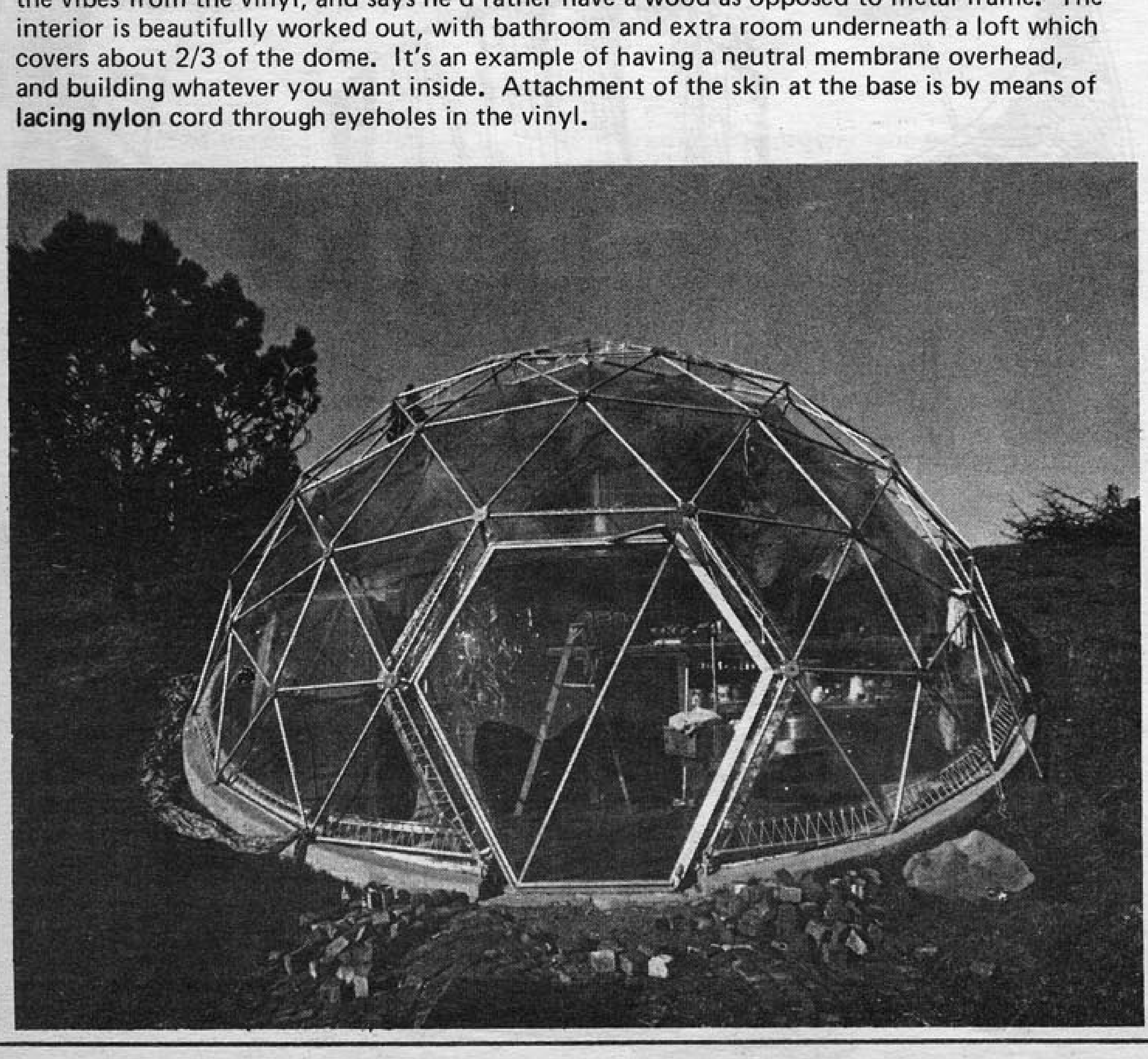
**TENTDOMES**
Tentdomes have been made by hanging one-piece flexible skins *inside* metal frameworks. A one-piece skin solves the waterproofing problems of trying to piece together many components, and a tent dome is potentially easily portable with quick-fastening devices at vertexes of the frame. In one sense a tentdome is better than an air building, as you do not need a blower and electricity to hold up the skin.

Portability is going to be useful for traveling roadshows, one-year communities, festivals. One of the best things about domes is the *process* of building, a lot of people working together, centering. Putting up Steve Baer's 40' zome at Alloy were dozens of people who'd never worked together before,building a white hemispherical shape in the New Mexico desert—a perfect way to start a meeting(Alloy was a meeting of communes, computer freaks, dopers, domebuilders etc. at an old abandoned ceramics factory in former Apache-Mescalero territory near La Luz, New mexico. It lasted about 4 days during the spring equinox 1968).

**FRAMES**
Electrical conduit, with ends crimped and drilled is probably the cheapest and simplest frame. See p. 42. An eyebolt can be used at the hub from which the skin hangs. One with a cast or forged eye will be less likely to open under load than the common type. Interestingly enough, a hanging skin loads the vertexes directly and relieves the struts from bending because the skin doesn't touch the struts. Thus it's stronger than if the skin were equally distributed over the entire frame.

Turnbuckles can also be used to hang skin from. The connectors of some of Fuller's tentdomes were adjustable so that the tightness of the skin could be adjusted.

Neill Smith's dome is a 30' 3/8 sphere, 4-frequency alternate playground structure, set on a hillside with a one-piece vinyl skin suspended inside from plexiglass washers. Attachment to the frame is with nylon cord, and the washers have been heat formed to the curvature of the dome. Washers distribute the stress over a large area of material and should have rounded off edges. Ventilation is by means of zippered flaps along the bottom, and there is no shade, and the dome heats up to unbearable temperatures in the sun; Neill says he's planning to grow ivy over the frame, trimming it back for windows. He isn't happy with the vibes from the vinyl, and says he'd rather have a wood as opposed to metal frame. The interior is beautifully worked out, with bathroom and extra room underneath a loft which covers about 2/3 of the dome. It's an example of having a neutral membrane overhead, and building whatever you want inside. Attachment of the skin at the base is by means of **lacing nylon** cord through eyeholes in the vinyl.



Baer's zome frame was 1½" or 2" fence pipe—this allowed him to have long struts, compared to a 3/4" conduit frame. The skin was hung from eyebolts with big rubber bands cut from truck inner tubes, attached to loops sewn onto the skin. The rubber allows the skin to move around.

Other hubs could be used for metal frames, and wood frames would work also.

Although hanging one-piece skins inside the frame seems simplest, there are other interesting possibilities:
—stretching a skin over the outside, although there could be problems from winds causing the skin to flutter against struts and wear down. However, this might be compensated for by using a double-stick tape between skin and struts. A wood frame could be used here.
—double skins, either with one inside, the other outside; or both hung inside, with spacers in-between.
—hanging the skin on the inside makes hyperbolic paraboloids, reducing flutter and vibration. To get hyperbolic paraboloids with the skin on the outside, you can use a diamond breakdown with the struts across the diamonds replaced with cable. Struts will be inside, cable outside.
—a 60' one-piece skin dome was built in Wisconsin that had a foot or so of threaded rod projecting out from each vertex. The skin was stretched over the outside—the tension was adjusted by a nut and washer on the inside and tightened down by a nut and washer on the outside. The diamond struts were replaced with cable—both cable and struts were on the inside.
—Fuller built a dome many years ago that consisted of two skins sealed together and compartmentalized—when inflated it was self-supporting.
—another way to get a curved surface with the skin on the outside is to use some sort of space frame. The spider frame is a partial space frame that will give a hyperbolic paraboloid surface.
—very shallow pillows could be built in to a one-piece skin—inflating would prevent vibration. The pillow domes would have been better if the pillows had been welded to each other.

# DOMES

## SKINS
There are many choices in material for skins. Tent canvas will last several years if treated for mildew resistance. Plastic coated fabrics last much longer and will withstand dampness better. Any fabric used should be *fire retardant* and any cotton based fabric should be pre-shrunk. Information we have on skin material is on p. 86. Also look in yellow pages under *Industrial Covers, Truck Tarpaulins, Pool Covers, Vinyl Fabricators,* or *Awnings.*

## INSULATION
The best way to avoid sun heat build-up is to have the skin be opaque—white or aluminized; this reflects the sun's rays. This will reduce heat as compared to a transparent or translucent skin, but for real insulation there are several choices:

1. If the skin can go outside the frame, as a washer hub wooden frame, insulation could be pop-in styrofoam panels—as shown on p. 84.
2. A double skin is possible, with insulating air space in between, or fiberglass(goose down?) filling the in-between space. The second skin could be of a cheaper fabric, such as muslin, as it won't have to take outdoor exposure. Muslin could be tie-died or batiked in places. The inner skin could be hung from the underside of the washers that hold the outer skin. There was a 12" dead air space in between skins of the large dome tent at the New York World's Fair. If condensation is a problem, there should be a means of draining water off the inner skin to outside the outer skin.
3. Heating and cooling can be handled by blowers, as is done in air buildings, but this is expensive, and uses a lot of resources.

### Calculating Size of Skin and Pattern of Pieces
Steve Baer calculated the inside-hanging skin of his 40' tent zome at a radius 2' less than the exoskeleton. If the skin goes *outside,* it would be at the same radius as the frame. Neill Smith's tent skin was made of diamonds, rather than triangles. This meant less heat welding seams. Try to calculate the skin piecing from as large pieces as is possible from the material.

Another possibility is to cut out "gores", the way a parachute is made, although wrinkles might be a problem.

Make patterns in a way that allows for stretch during fabrication, and for the difference in stretch between "warp"(the long direction on a roll of material) and "weft" or "fill" (the cross-roll direction). Fill direction may stretch as much as 8 times more than warp. This applies to plastic as well as canvas materials; with the plastics the warp is called "machine direction" (MD) and the fill is called "transverse direction" (TD). The "bias" (diagonal) will stretch even more. your supplier can tell you what to expect.

Seams, being double thickness, will stretch less than the main body of the material. You'll also have to make "seam allowance" for overlapping during fabrication. This is about 5/8" with awnings, but differs with each type of seam and the joining technique. This can get tricky, and it's a good idea to consult a tent or sailmaker.

## VENTING A ONE-PIECE SKIN
There are three or four different ways to manage air-flow that I can think of. First, you can do as Neill Smith has done: have a secondary skin around the bottom that is not in tension that has opening vents built-in. A similar idea is to use a low(or maybe even high) truncation with non-structural walls set back. The skin will extend beyond like the eaves of a house.

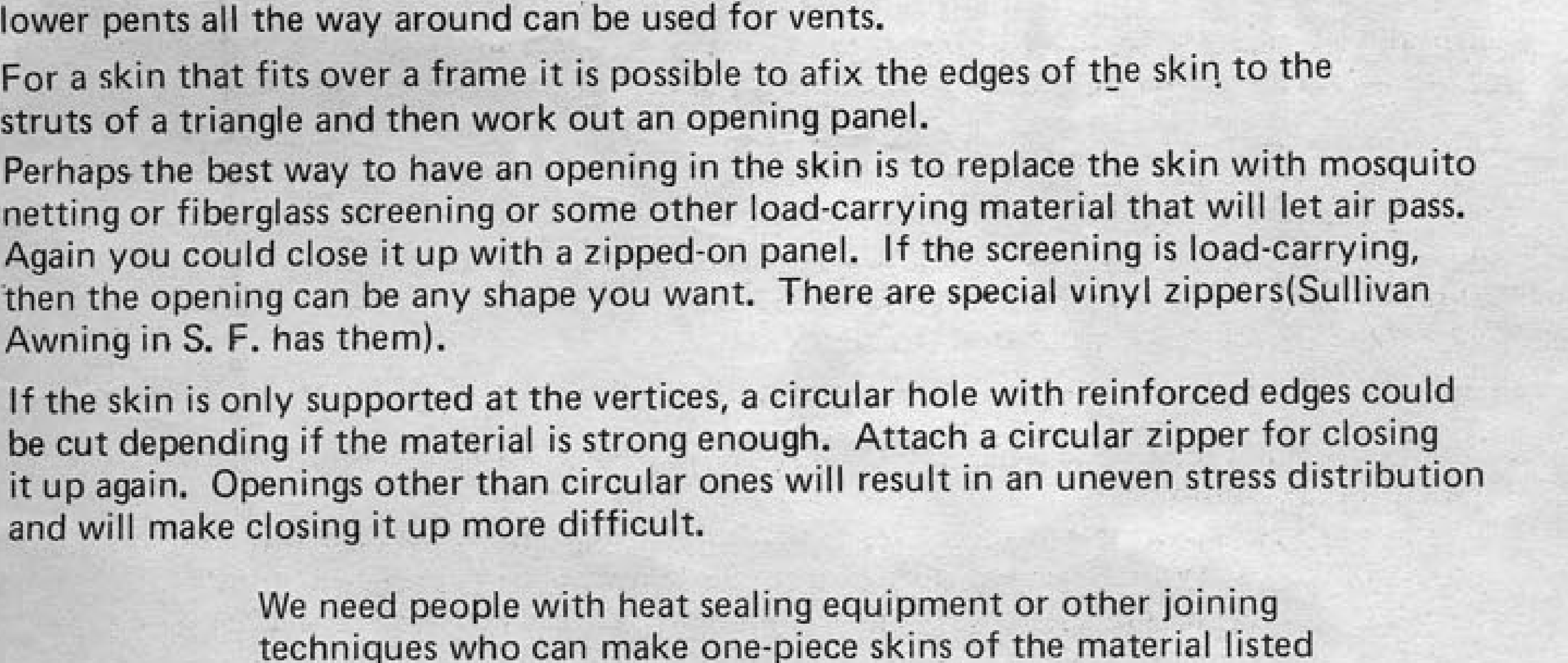
One of the best ways to ventilate is to leave the top pent(or part of the top pent) open, with a larger pent with skin superimposed on top. The distance between the top and lower pents all the way around can be used for vents.

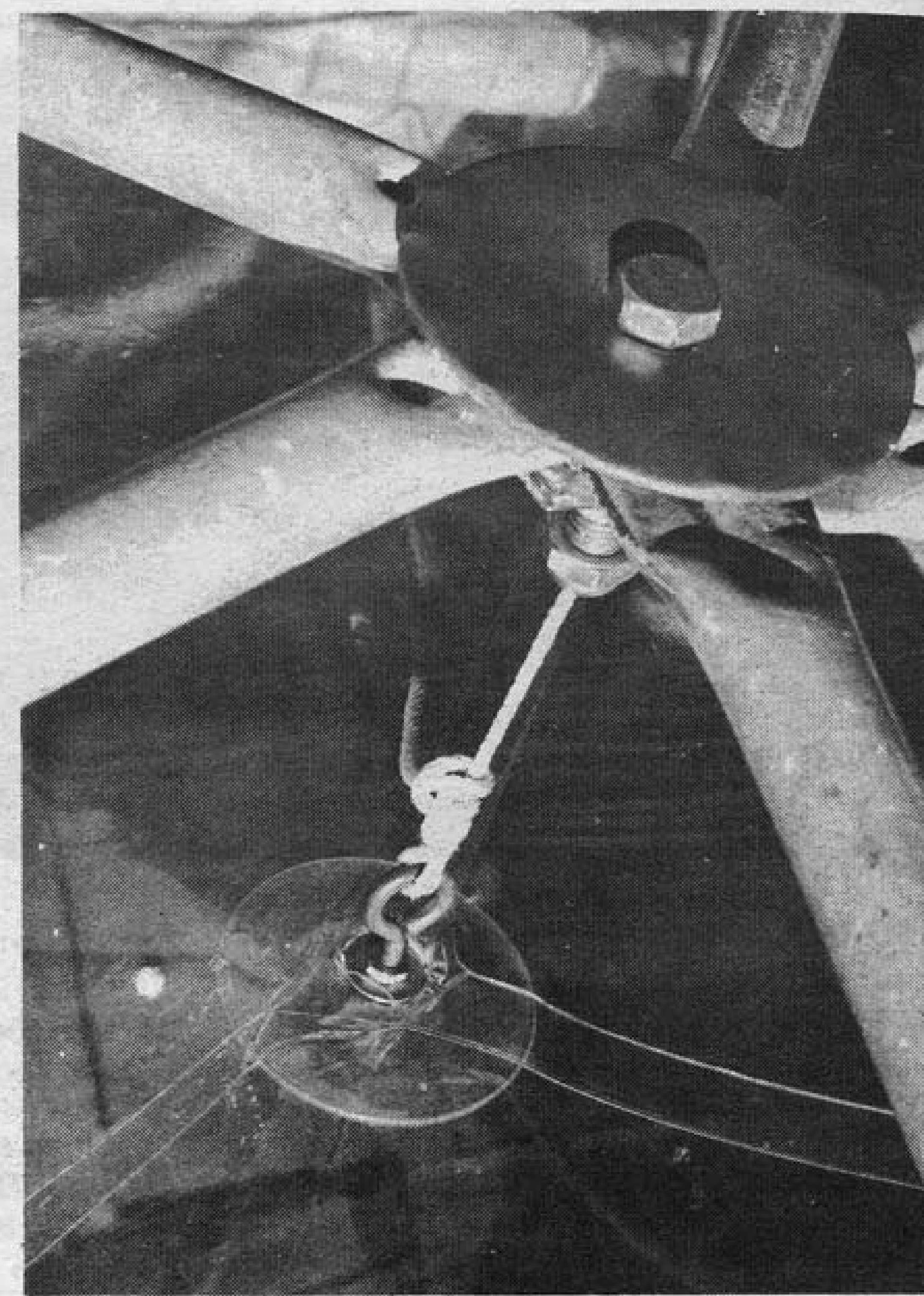
For a skin that fits over a frame it is possible to afix the edges of the skin to the struts of a triangle and then work out an opening panel.

Perhaps the best way to have an opening in the skin is to replace the skin with mosquito netting or fiberglass screening or some other load-carrying material that will let air pass. Again you could close it up with a zipped-on panel. If the screening is load-carrying, then the opening can be any shape you want. There are special vinyl zippers(Sullivan Awning in S. F. has them).

If the skin is only supported at the vertices, a circular hole with reinforced edges could be cut depending if the material is strong enough. Attach a circular zipper for closing it up again. Openings other than circular ones will result in an uneven stress distribution and will make closing it up more difficult.

> We need people with heat sealing equipment or other joining techniques who can make one-piece skins of the material listed above. If you know of anyone who can do this, let us know; it could entail distribution to quite a few prospective dome builders.





## FABRICATION
We have had trouble finding people who will make up one-piece skins. The companies who who electronically seal materials like vinyl generally have stationary equipment, so have to move the heavy skin around to add new pieces.

There are a few companies who have had experience making skins for domes, but it's expensive(see p. 86).

The lack of manufacturers and the expense is not such a problem anymore since there are a number of good ways to make your own.

### Sewing
The first people I talked to about making a one-piece skin were Alameda Awning in San Jose. They use a lot of Armor Shell, which is a dacron fabric(like fine flexible window screen) with a PVC plastic coating. It's used in awnings, and reportedly holds up well in the weather. It comes in a 54" width. Their price was $3 per triangle for a 24' dome for labor and materials using 10 oz. Armor Shell.

You can probably sew your own canvas skin by renting an industrial sewing machine. A combination of glue and sewing is good on nylon or dacron fabrics for waterproof joints. Bonded polyester thread is a dacron tent thread which is strong, does not rot in sun or rain, and will not wick water.

Sailmakers are used to handling large pieces of material and usually have different weights of dacron and nylon available. Maybe you can cut the pieces out and have them do the sewing.

### Taping
Films like mylar can be taped together. Mylar doesn't last very long in the sun, but you can make the skin yourself using 3M No. 850 tape— the bond is almost as strong as the film and there is no detectable creep.

### Gluing
This would be ideal if it worked. We haven't tried any gluing tests. If you could glue the fabric together, you would eliminate the necessity of running it through a machine. The question is whether the glue is strong enough. Schjedahl makes a thermoplastic tape which is sealed with a hand iron. 3M has some very strong adhesives. Swirles and Company has what they call a "life span adhesive formulation", and "...dead load tests on a 1½" seam at 50 lbs per inch for 4 hours have been attained at 158°F." See p. 86.

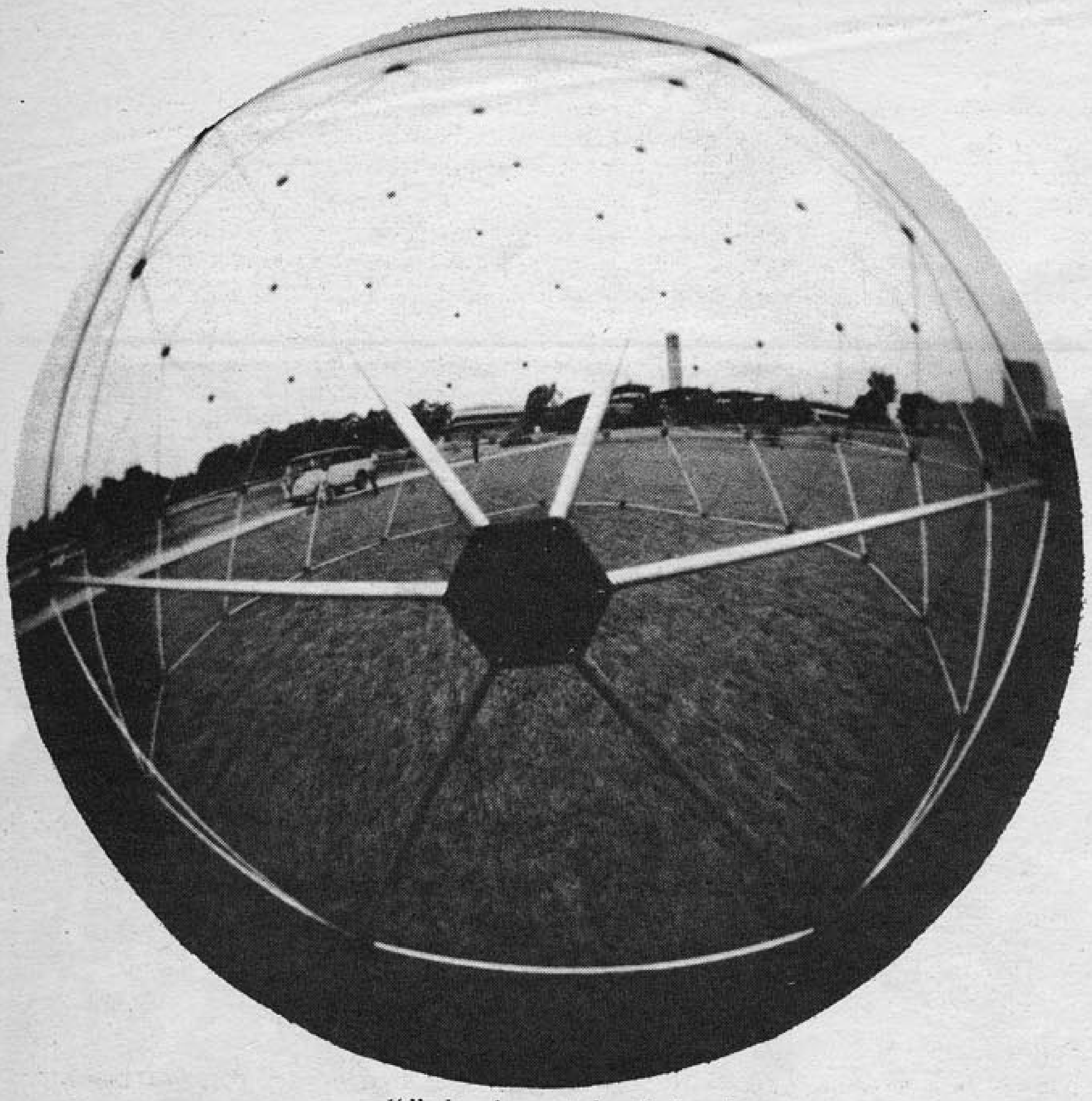
### Welding
Heat sealing or electronic welding is done with a relatively expensive machine. The weld is as strong as the material, and it's the best way to join plastic or plasticoated fabrics. In the San Francisco area, we've had trouble finding people with the equipment who will make large one-piece skins. On the other hand, the large companies, like Industrial Covers in S. F., that make huge one-piece skins(up to 114,000 sq ft) are reluctant to fool with relatively smaller skins. Best would be if someone set up especially to manufacture 1,000-2500 sq ft skins for dome builders. Andy Shapire of the Ant Farm has been talking about doing this. If you want to check with him see p. 118.

### Ultrasonic Sewing
You can rent an ultrasonic sewing machine for $300 per month(minimum) that sews most synthetic materials, woven, non-woven, or film without needle and thread at rates up to 50' per minute. You can sew polyester, nylon, polypropelene, polyethelene, acrylics and vinyls. We don't know if the bond is strong enough for a skin.

### Zippers
Steve Baer's tent zome consisted of triangles and rhombuses that zipped together. This is expensive, but allows for flexibility in openings and shapes, and easy portability of the skin.

There are special zippers for vinyl and plastics that do not have teeth, but that grip specially heat formed ridges in the plastic. Sullivan Awning in S. F. has such zippers.

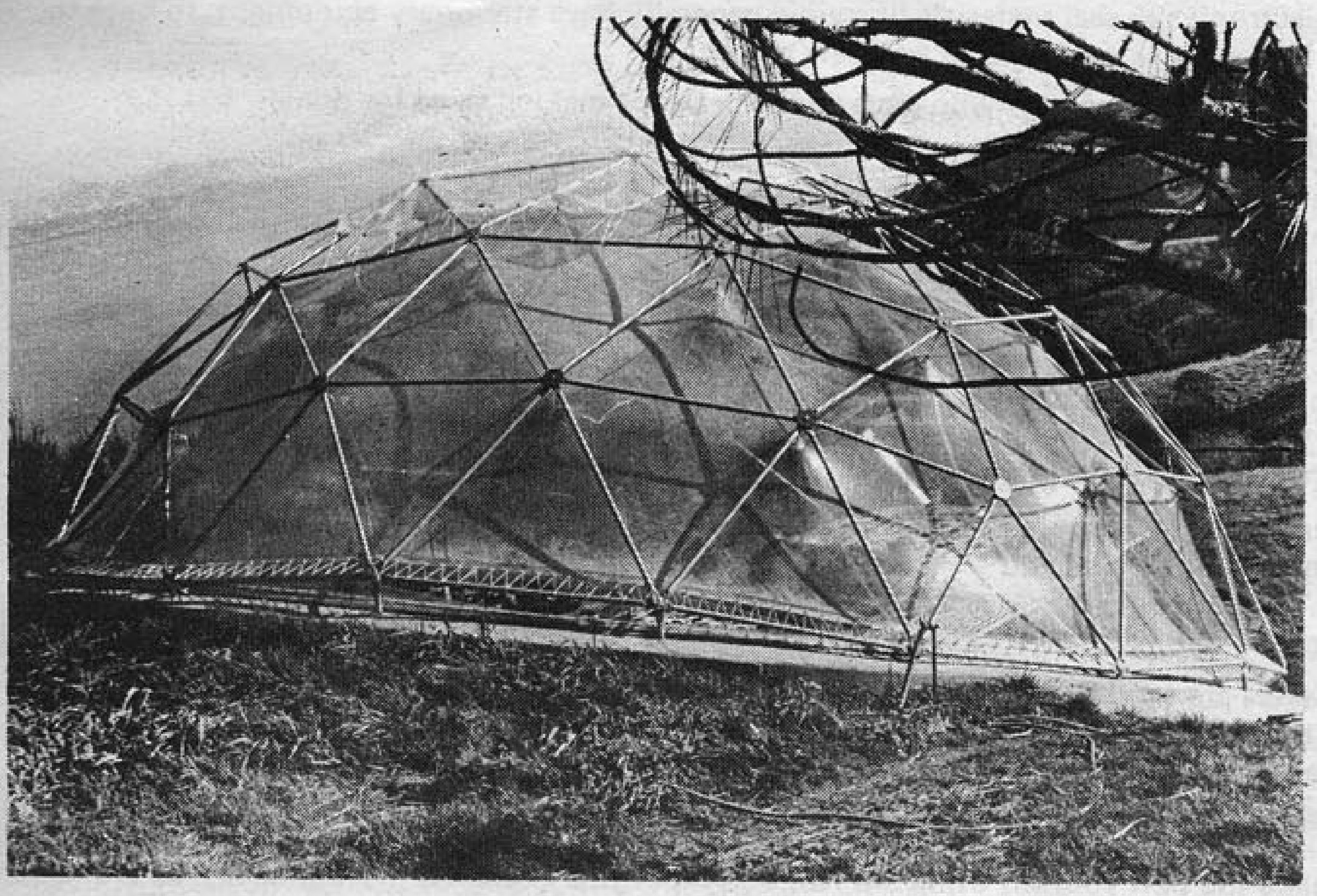
# TUBE FRAME DOMES



*½" aluminum tube skybreak*

The tube frame can be used as a skinless "skybreak", as the support structure for one-piece membranes, or for fiberglass sheet, plexiglass or plywood panels. It could also be used as the main structural support for a ferro cement mesh or foam-on fabric.

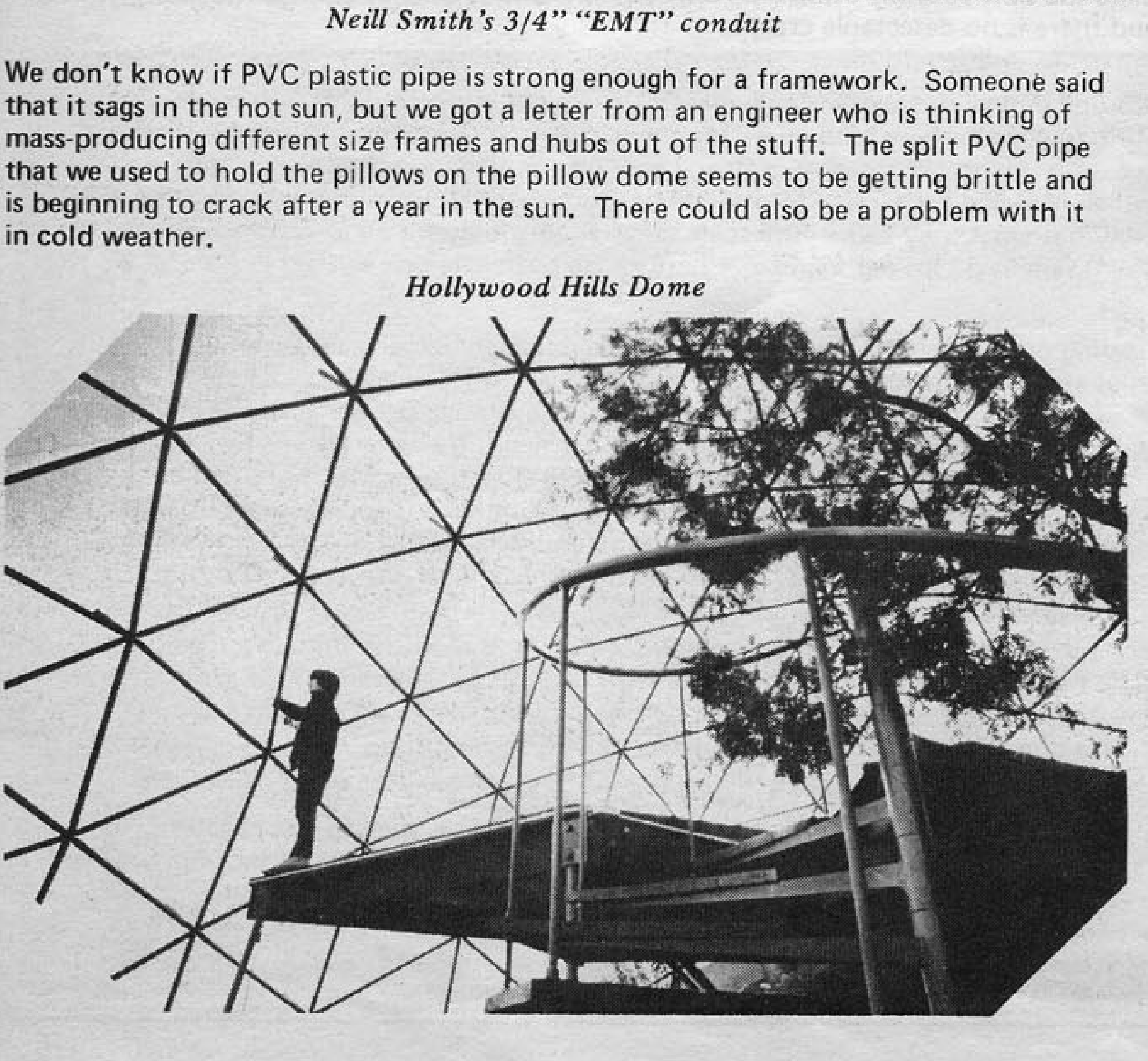
The kind of tubing to use depends upon what you want to do. The pillow dome and Neill Smith's dome both used 3/4" "EMT" thinwall conduit. It is easy to work with and is plated so that painting isn't necessary. Bob Easton used ½" aluminum tubing to make a 24'3-frequency skybreak, which weighs 60 lbs including plywood hubs.



*Neill Smith's 3/4" "EMT" conduit*

We don't know if PVC plastic pipe is strong enough for a framework. Someone said that it sags in the hot sun, but we got a letter from an engineer who is thinking of mass-producing different size frames and hubs out of the stuff. The split PVC pipe that we used to hold the pillows on the pillow dome seems to be getting brittle and is beginning to crack after a year in the sun. There could also be a problem with it in cold weather.

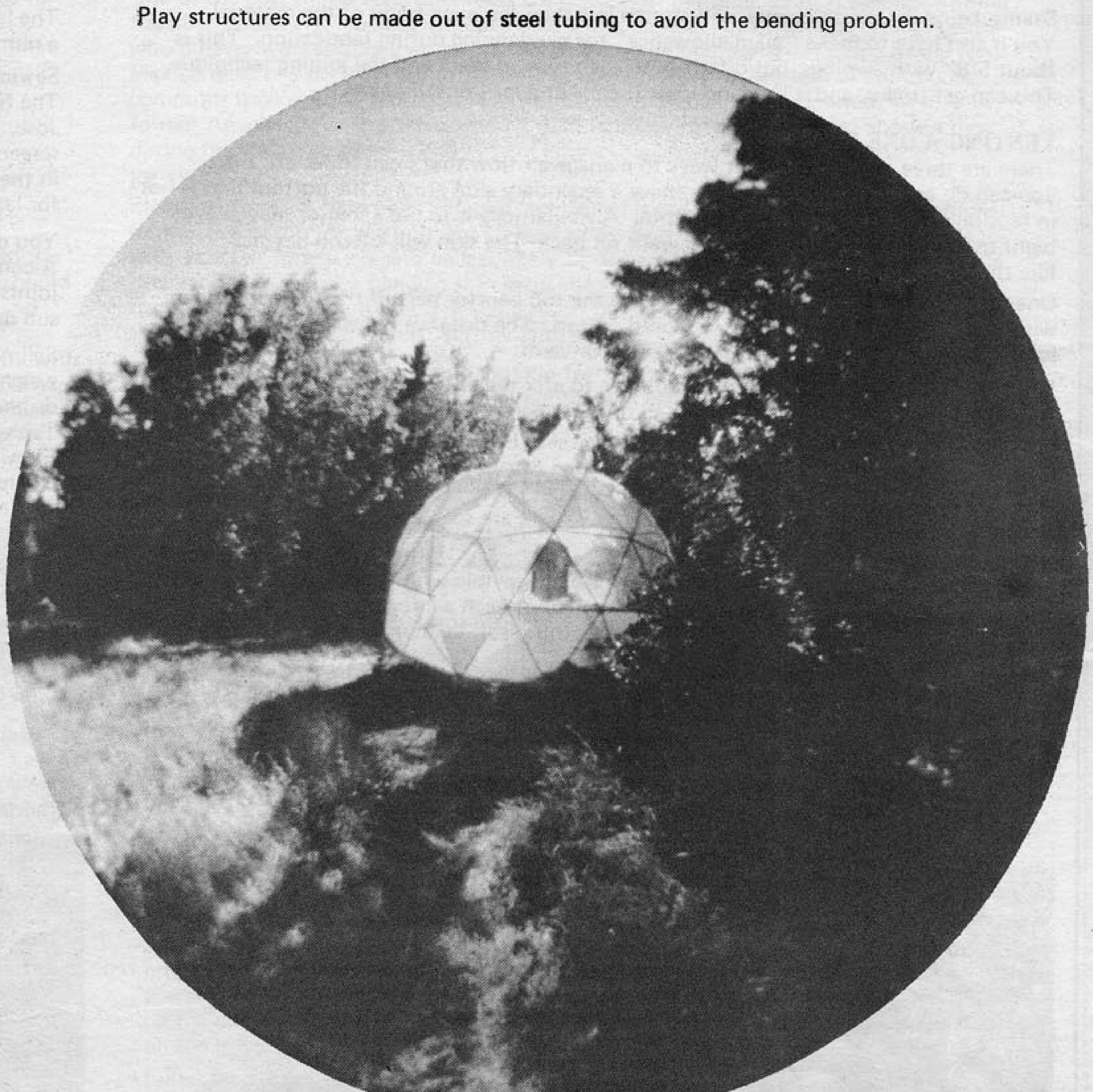
*Hollywood Hills Dome*



*Pillow Dome*

Aluminum tubing is two or three times more expensive than steel. If lightness and corrosion resistance are important, it might be worth it. Aluminum is usually sold by the pound with reductions in cost per lb if you buy more than 100, 300, 500, or 1000 pounds.

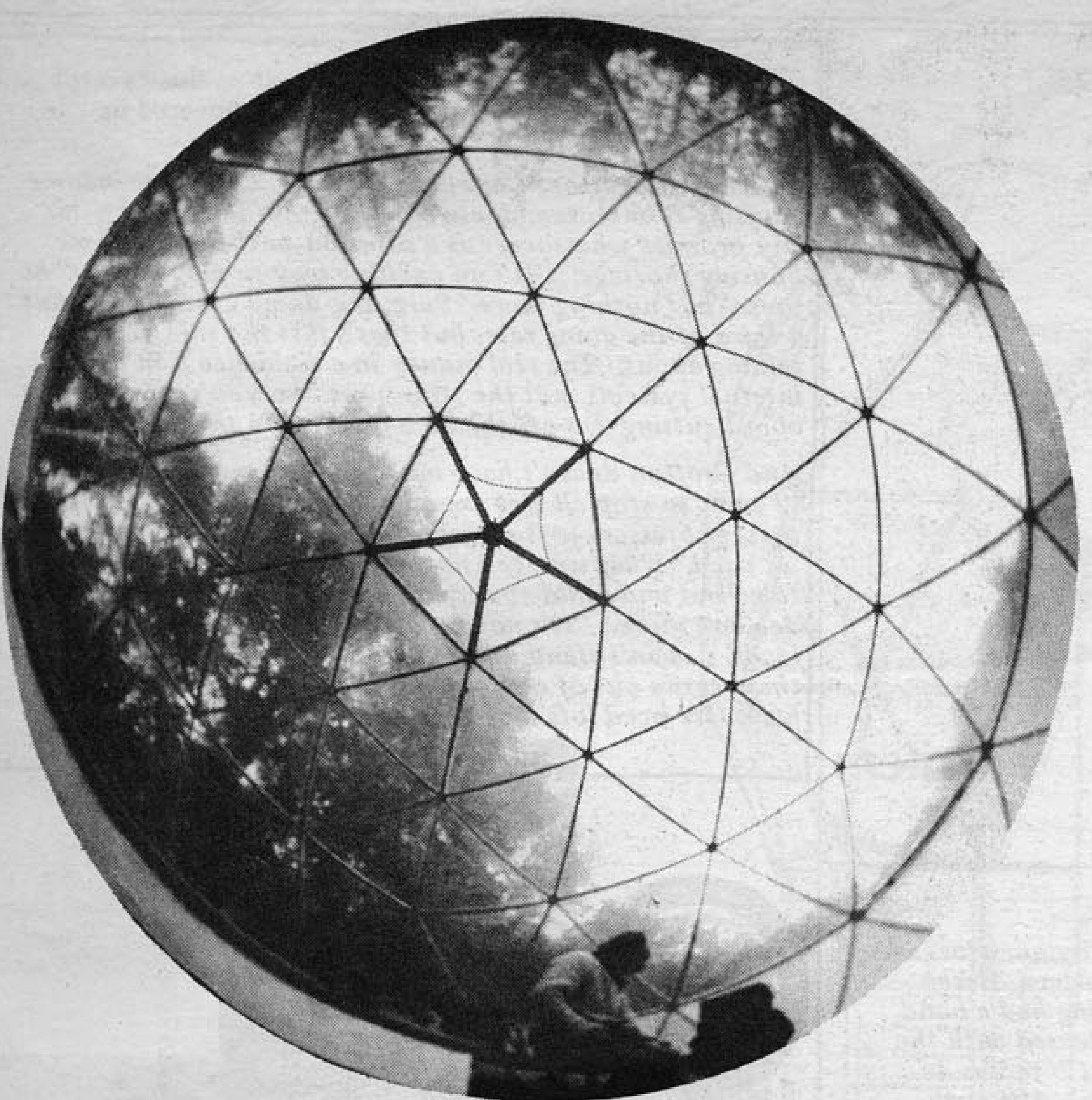
Play structures can be made out of steel tubing to avoid the bending problem.

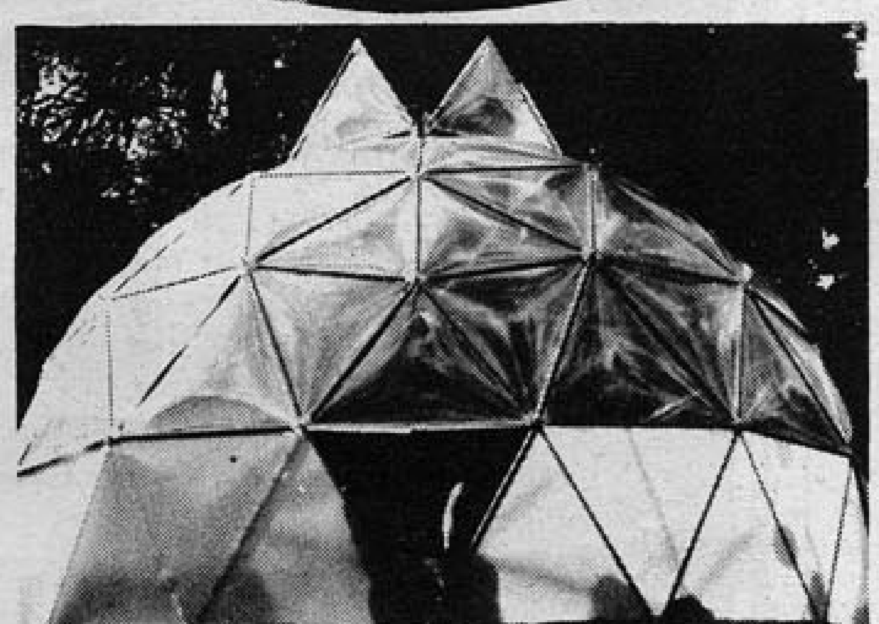


*Pillow Dome*

You can climb on 3/4" conduit frames as long as you don't step near the middle of the struts. ½" conduit would probably be strong enough to support the loads on a 20' dome, but you have to be more delicate and precise in working with it.

 Tubes with squashed ends don't need separate hubs—they can be easily erected and transported.





# TUBE FRAME DOME

These are instructions for making a tube frame of thinwall conduit. They can be adapted for making frames of steel water pipe, or fence post pipe, in which case a hydraulic press is needed for squashing. A spectacular 40′ 4-frequency alternate 5/8 dome was made of 3/4″ water pipe in Isla Vista recently; the pipe is so thin in relation to the dome's size that it looks very spidery. If you have a method of squashing tubes, this is probably the simplest way to make a full size dome frame. Tube frames can also be used for jungle gyms, if you file off all sharp edges.

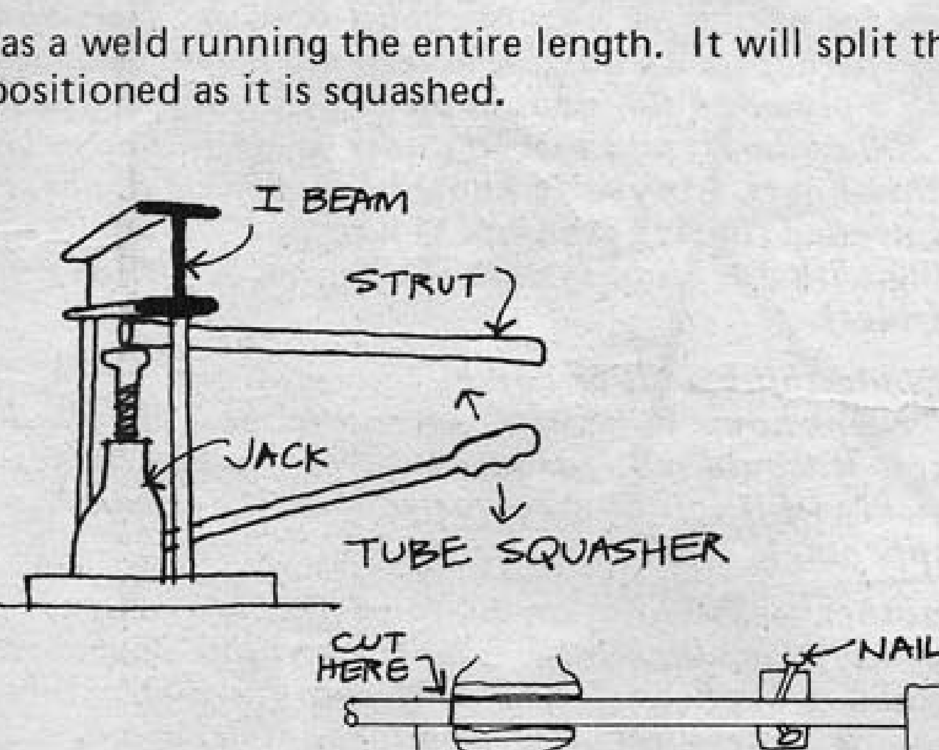
**Cutting**
Add 1½″ to the strut lengths if you are going to use squashed tips as a hub. This will leave ½″ of metal between the hole edge and tip of the strut. Other types of hubs will require different allowances.

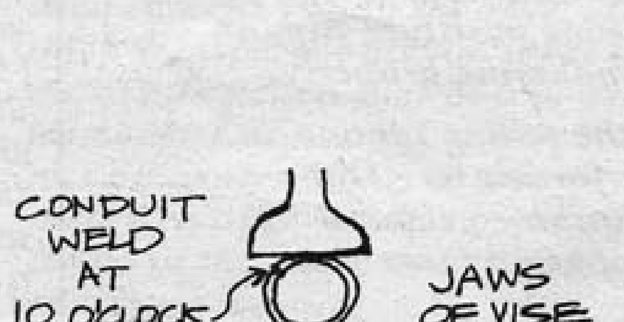
Conduit comes in ten ft. lengths. Sometimes it's possible to get damaged pieces from a large supplier for less. Choose a dome size that will minimize waste. You can get a slightly larger frame by combining a long strut and a short strut in a 10 ft piece.

Try to get your tubes cut for you at a place with a cut-off saw. If you can't manage that, a hacksaw is faster than the fiber blades for table saws, and leaves a better edge. Hold the tube in a vice as shown, with a stop. Cut right at the jaw. Use a 16 or 18 tooth highest quality short blade.

**Squashing**
Flatten the tips about 2¼″ from the end. The exact distance will depend on what size tube you are using. Be sure that the tips allow enough clearance for a tight stack. Squeezing tubes in a vise has broken all our vises. Heating the tube tips with a torch first makes them easier to squash in a vise, but it ruins the plating and the tips will rust. It seems best to find someone with an arbor press or, better, an "Enerpac". You can make a crude one from a hydraulic car jack this way:

Conduit has a weld running the entire length. It will split there if the weld is not properly positioned as it is squashed.




Make sure the squashed ends are in the same plane.

Cracks in the metal across the center of the tip are acceptable. Cracks along the edge of the tip are rejects. "Lips" should be removed with a hammer whack or the stack will be too high. Doing th entire job accurately and neatly with a hammer is hard, but if you don't care, it can be done this way.

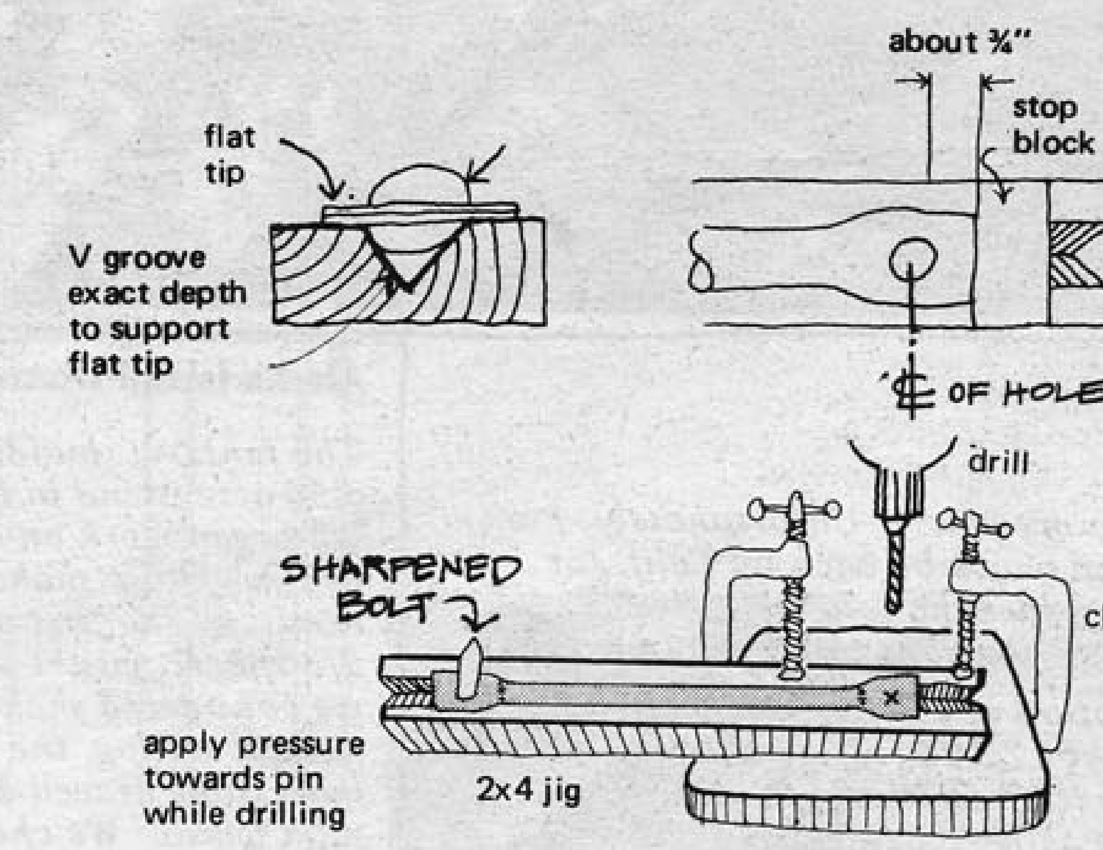
The tips should be filed off and rustproofed with "Galvanoleum" or "Cold Galv" paint.

**Drilling**
To drill the hub bolt holes, make a jig by cutting a V groove in a 2 X 4 and clamping it to the drill press:

The stop block makes sure the hole is the correct distance from the tip on all pieces. Drill the holes 1/32″ oversize. Keep the piece tight against the stop, and make sure chips aren't holding it away from the correct position.

To drill the second hole, countersink a carriage bolt so that is comes up through the jig. Clamp the 2 X 4 in a position so that the distance from the center of the bolt to the drill bit center is exactly the chord-factor distance for that strut size. A good way to adjust the jig accurately is to lightly clamp it to the drill table and then tap it into position with a hammer. You should be sure to hold every piece against the carriage bolt to take up any slack. An accurate drill job will make assembly easier. With rigid skins, it is essential for a good waterproof fit of the panels.

Other holes can be drilled in the tubes by repositioning the jig.




**Bending**
The tips can now be bent to about $10^o$. Unless the tubes are very stiff they will bend automatically to the exact angle as you assemble. A vice can be used to do this.

**Hub bolts**
Hub bolts should be long enough to go through a stack of six flattened tips plus two washers plus enough to get a nut onto easily. Using an eyebolt means that you will have handy places to attach things in the dome. Using bolts that are several inches longer than necessary gives you a footrest for climbing, and also gives a threaded place for attaching things to the outside of the dome, such as sunshades. If you use eyebolts, be sure that they are threaded down near the eye, or you'll have to use a nut on both sides of the stack.

The stack can be made in any way that makes sense, but we like to stack symmetrically so that things come out the same all the way around. A 3/8 eyebolt is strong enough to take several hundred pounds. Smaller ones bend more easily.

**Assembly**
Assemble the frame by starting at the bottom. Starting at the top and lifting as you go is tricky unless you can figure out a good way to lift it evenly all around. In most cases, the frame will not need additional support as you work.

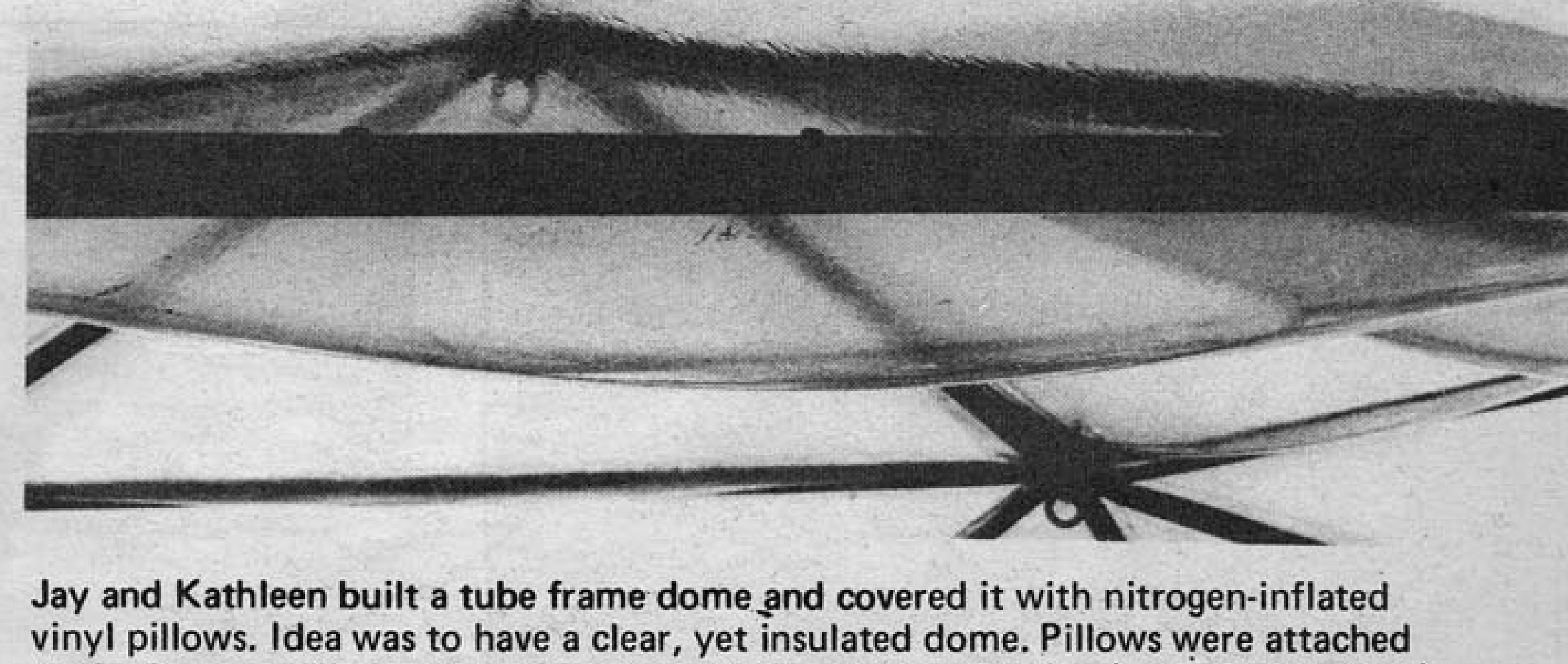
**Anchoring**
It's probably best to anchor the frame before skinning it if you live in a windy area. There's more on anchoring in the Wind Load section.

**Skinning**
One-piece skins, pillows, and sheet stock can be used for skinning. Sheet stock, unless it is plyable, will work better on tube frames with smooth hubs instead of the stacked squahed ends.

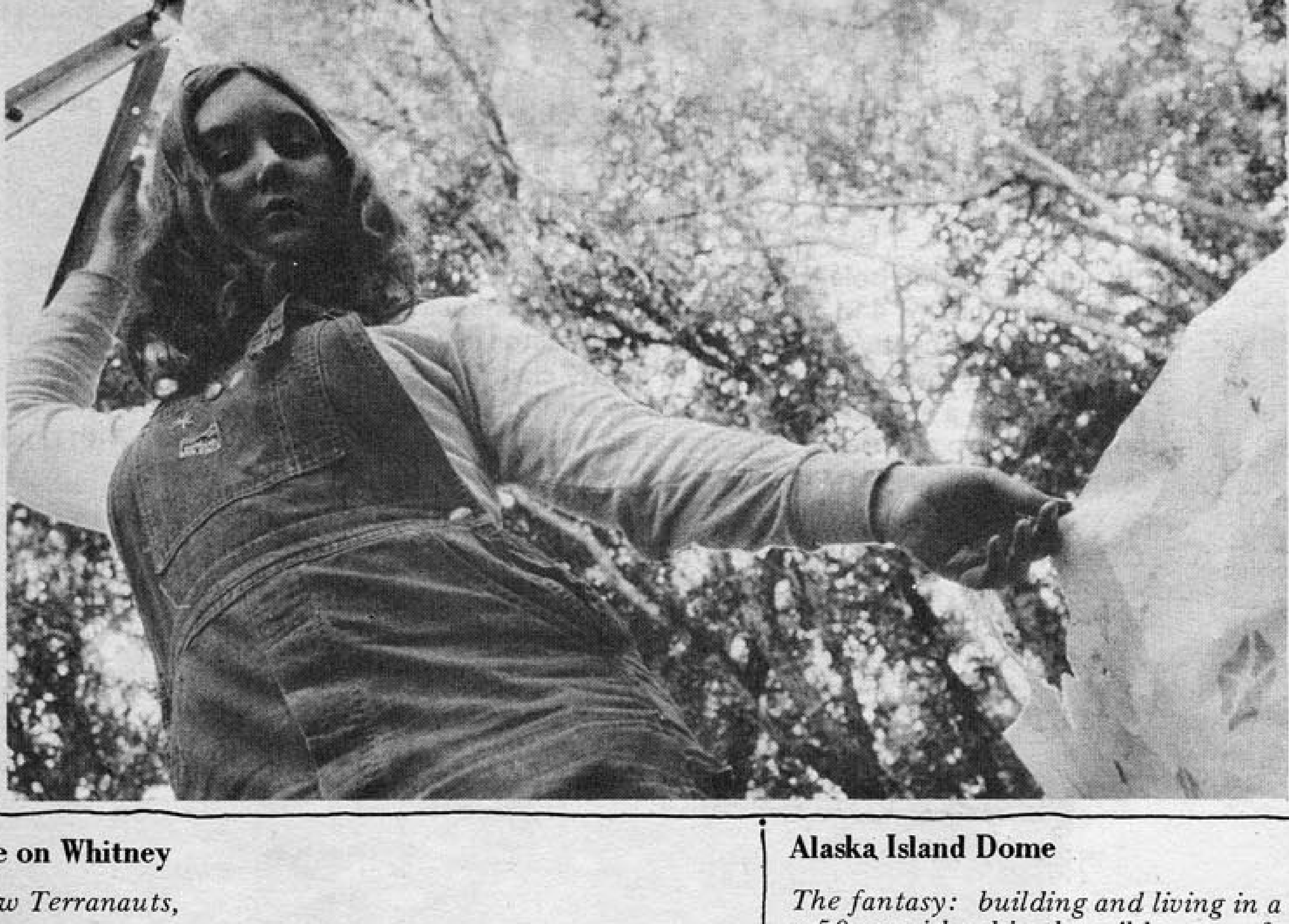
Sheet metal can be pop-riveted onto the frame with the triangles shingled. The overlapping material could be bent on a brake to make the waterproofing easier. A strip of butyl caulk can be used between the triangles. A nylon gasket can be used between layers of metal—it might be the best bet if you can find out more information about it.

There are problems of expansion and contraction with this type of dome. Expansion causes the skin to bulge between the fasteners and break away from the caulk. You can use oversized holes in the skin but then there will be a water-proofing problem.

A hollow hub could be designed to house electrical outlets with the wire running through the struts. A die for a cast hub will be about $100. The hubs will cost about a dollar apiece if made out of aluminum.



Jay and Kathleen built a tube frame dome and covered it with nitrogen-inflated vinyl pillows. Idea was to have a clear, yet insulated dome. Pillows were attached to the frame with a split piece of class 125 ¾.. PVC water pipe (cut on a bandsaw), and sheet metal screws clamping the vinyl to the tubes.



writers

*Time* correspondent Robbin Ahrold sent us this excerpt from his notes for article on domes that appeared in *Time* March 1, 1971:

*Edward G. Grafton, Chairman of the A. I. A. Low-income Housing Committee, doesn't believe that the dome holds any promise whatsoever as a solution to the low-income housing shortage. "It's an exciting way to play games," he says, "but nothing more. Sure, the dome costs only about a third of the going rate, but that's just the skin you're talking about. The real money in a residence is in the internal systems, not the structures. So you're just talking about cutting 2/3 off the 20% invested in the skin."*

*And Grafton doesn't have much faith in men like Fuller. "I want to stop all this experimenting, all this research, all these professors writing reports. We have all the technology we need. What we need now is for some free-enterprisers to go out and build—build—build." His voice raises a few decibels more. "It's not functional, it can't stand solar loads, it won't stand up in high winds, and you can't build them easily out of concrete. Concrete is our thing down here. We need lots more concrete housing."*

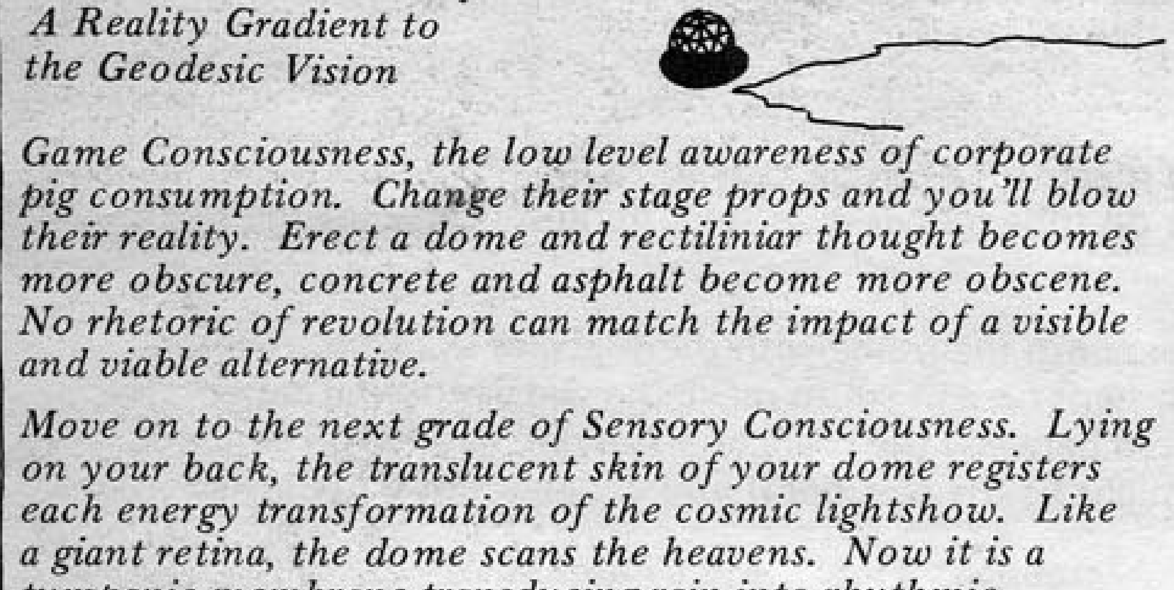
## Dome on Whitney

*Fellow Terranauts,*

*Thank you for replying to my letter. Unfortunately, I am presently in New York and won't be back by Calif. for several months. Please consider the following free associations as possible contributions to* Domebook Two.

*The following is a description of a 3-frequency alternate dome which was erected at 12,100 feet on the west slope of Mt. Whitney. The structure utilized 1/8 inch wood doweling as struts (max length 18 inches) and 3/4 wood doweling as joints. The joints, both 5 and 6 sided, were drilled and then cut after the fashion of tinker toys. The dome, which measured 8 ft across, was then assembled in a room and fitted with a 6 mil polyethelyne skin. The structure was then disassembled and rolled up into a 6 lb package which was easily transported by backpack. It took about an hour and a half to cut all the parts and another two hours to fit the skin. Three 4 ft wide strips of plastic were joined together with 2 inch wide poly tape to form the roof and floor of the dome. A 4' X 6' "emergency blanket" of aluminized mylar was fitted between the skin and the struts to shield against solar radiation.*

*The dome was then packed over Mt. Whitney trail to the Hitchcock Lakes area on the backside. Living in the dome was an unending education in planetary consciousness. The night before the Summer Solstice I left the comfort of my dome and climbed Whitney by starlight. Arrived at the summit (14,495 ft) and watched the Sun rise out of Death Valley. When I got back to the dome that afternoon, it was destroyed, the victim of inadequate anchoring.*



*A Reality Gradient to the Geodesic Vision*

*Game Consciousness, the low level awareness of corporate pig consumption. Change their stage props and you'll blow their reality. Erect a dome and rectiliniar thought becomes more obscure, concrete and asphalt become more obscene. No rhetoric of revolution can match the impact of a visible and viable alternative.*

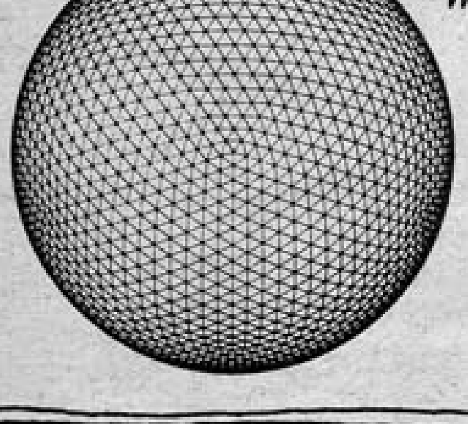
*Move on to the next grade of Sensory Consciousness. Lying on your back, the translucent skin of your dome registers each energy transformation of the cosmic lightshow. Like a giant retina, the dome scans the heavens. Now it is a tympanic membrane transducing rain into rhythmic meaning. You merge with the dome, its skin becomes your skin, and together you are a creature of tactil delight.*

*Now on to Cellular Consciousness and the awareness that your shelter follows the blueprint of your own cellular body. There is even a quality of life to the way the dome stretches and heaves with each breath. Above all, there is a niche for your dome in the community of life.*

*At the Molecular level, you see that you are indeed a respectable member of the community of life. You realize that your dome is a macroscopic molecule evolving out of the DNA spiral. Man, the protein matrix of three trillion DNA body cells, now spins a cellular exoskeleten.*

*And thus, at each reality, the Geodesic Vision persists. Beyond the reality of games and stage props, your dome is reasuringly real. Beyond any aesthetic notion of what constitutes good architecture, your dome makes sense. And beyond any psychedelic diatribe, such as this, your dome follows the Holy plan of all life.*

*Steve Kubby*
*Woodland Hills, California*



## Alaska Island Dome

*The fantasy: building and living in a dome by ourselves on a 50 acre island in the wilderness of southeastern Alaska. We began work on our own dome after having had a hand in Jim's cedar shake dome (p. 59). Quite pleased with the results of the first dome, we used the same 12' radius 4v 2/3 sphere, gusset plates and 2 X 4 members. Although we considered shakes the most desirable covering for a natural setting, the Alaskan location made shakes inaccessible as well as incompatible with expected 40-60 mph winds. We chose a ¼" exterior plywood skin to be sealed with tape and hypalon from Gaco Western.*

*Using a radial arm saw and an electric drill, the two of us cut the members to length, sliced and bored the ends, and cut and bored the gusset plates in 3 days. We used the same tar and thinner solution as Jim to stain all the parts a warm dark brown.*

*With ratchets in hand, six of us merrily bolted the dome together in 8 hours. After the dome was up we color coded the members and gusset plates for foolproof assembly on the island. We then disassembled the whole dome in 2 hours.*

*We pre-cut the plywood skin, having determined with scale patterns of the 8 different sized triangles the most efficient use of the 4 X 8 plywood sheets. Cutting the 55 sheets, 8 sheets at a time, took us 1 day with a skill saw.*

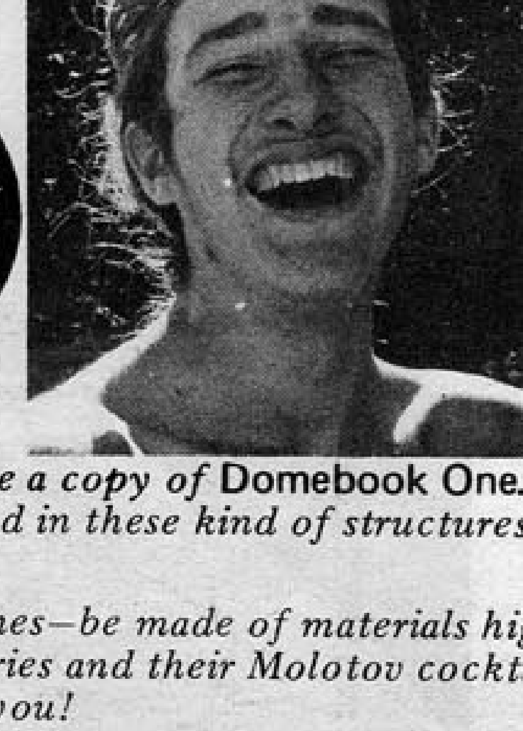
*With the dome all cut out and other essentials taken care of, we were ready for the move. Making a lattice work out of the 2 X 4 members, we formed the walls of a trailer which we then loaded with all. We rolled the trailer on to a ferry and headed for Alaska. We hoped to find a large enough stone area on the island to make the floor, thus eliminating foundations, etc. Not so. We chose a spot where the dome would blend, nestled in the trees and mossy cliffs. And built a deck. On top of pilings we formed a joist system of 3 X 12 beams and covered it with 2 X 8 planking, in a pattern radiating from the center. Deck completed, the dome rose once again. It took the two of us 3 days this time to erect it.*

*The bare frame was so beautiful in its setting that we were reluctant to cover it. But out of necessity we began putting on the plywood skin—closing in the dome and closing out the trees, sky and sea. Ten days of plywood installing was a tedious, unrewarding job. This was mostly due to dissatisfaction with the medium which was flimsy, unaesthetic and soulless. So we looked forward to covering the plywood with the hypalon paint. First neoprene paint was sloshed on with a long handled roller. It was extremely thick and dried quickly (15-30 min.). The joints were taped and another coat of paint was applied. The dome seemed totally emersed in a monolithic skin of neoprene—like a drop of oil on a pebble. As a test before the final coat of hypalon we, for the first time, anxiously awaited rain. And to our dismay it came right through to us standing inside, for it leaked at every seam.*

*Later consultation with Gaco yielded a tentative explanation: the extremely humid conditions in southeastern Alaska placed an invisible moisture film on the hypalon, preventing the tape's adhering properly.*

*The weather would not wait, and the falling snow foreclosed the hope of a dry dome for winter. Our thoughts turned to bright spring sunshine evaporating that invisible moisture film, new tape and more time.*

*Fern and Forest*



## Really Sharp

*Kindly send me a copy of* Domebook One*....I am very much interested in these kind of structures. They are really sharp.....*

*Can they—domes—be made of materials highly resistant to revolutionaries and their Molotov cocktails, etc.? Will close. Thank you!*

*Moose (Howard Crawford)*
*Fontana, California*

## Strafed

*I got your thing in the mail and here's my big news. Our trip in Topanga is mostly downers, because of the large scale hassles we're getting from the sheriff's department. Whenever we put up a dome, the county inspector tends to appear within hours of completion, followed shortly by the county fire patrol...all with the usual threat of fines, fire hazard, etc.*

*So, we tried building back in the brush, avoiding any open sunny prime locations...which worked for a week until one day, one of the many sheriff's patrol helicopters came out of nowhere—dropped a smoke bomb nearby and here came the inspector and company.*

*That damn helicopter came over the hill at about 50 ft, screaming threats through their bullhorns until the dome was removed. You can't see or hear them coming until they're right on top of you. I imagine the Vietnamese discovered that fact some time ago. It tends to be quite intimidating and effective. I've also been working on self-sufficient systems, in spite of the easy proximity of local utilities. Not only do I wish to be as free as possible of the local consumer society, but it is the usual first control the building department exercises over your structure....no permit, no utilities.*

*The Dunlite (Australian) system seems to work very well, but it's still way expensive for the normal consumer. Land-rovers (like mine) can be adapted to use power tools and generate electricity (through their power take-off motor) until your system is set-up. In the canyons of Topanga and Malibu, there is usually always wind-power available and ready to be harnessed.*

*As for water, those Japanese Cecoco hydraulic pumps work well. I saw them working in Japan in 1964. If you coordinate it right, using one of those shipboard or non-chemical camper toilets, you can convert it (the shit) into methane gas power (as well as fuel for your compost heap).*

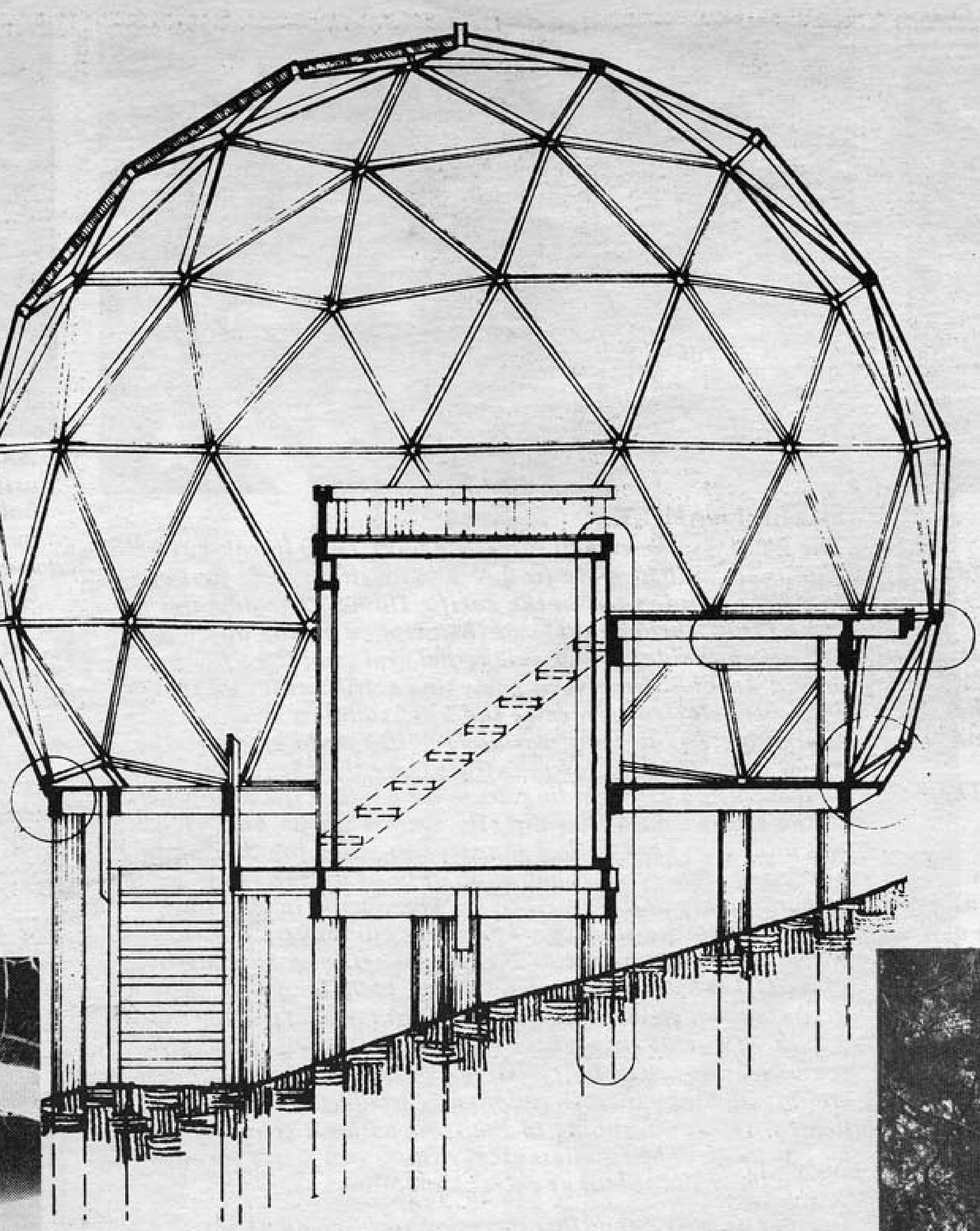
*What we need right now is a good-sized geodesic dome tent (perhaps with outside aluminum frames?) which with a plywood floor could be thrown very inexpensively (1-200 dollars?) and moved under pressure to a new site within hours. Anybody know of this being done? Patterns are needed (liners? as in tipi's) now as it's a whole new thing with a tension system (Fuller did it for the army-marines).*

*I would think a kit or complete tent would be an excellent home industry for a commune / family...I know it would sell—for sure it would spread domes quickly (if it can be done faster than it's already happening).*

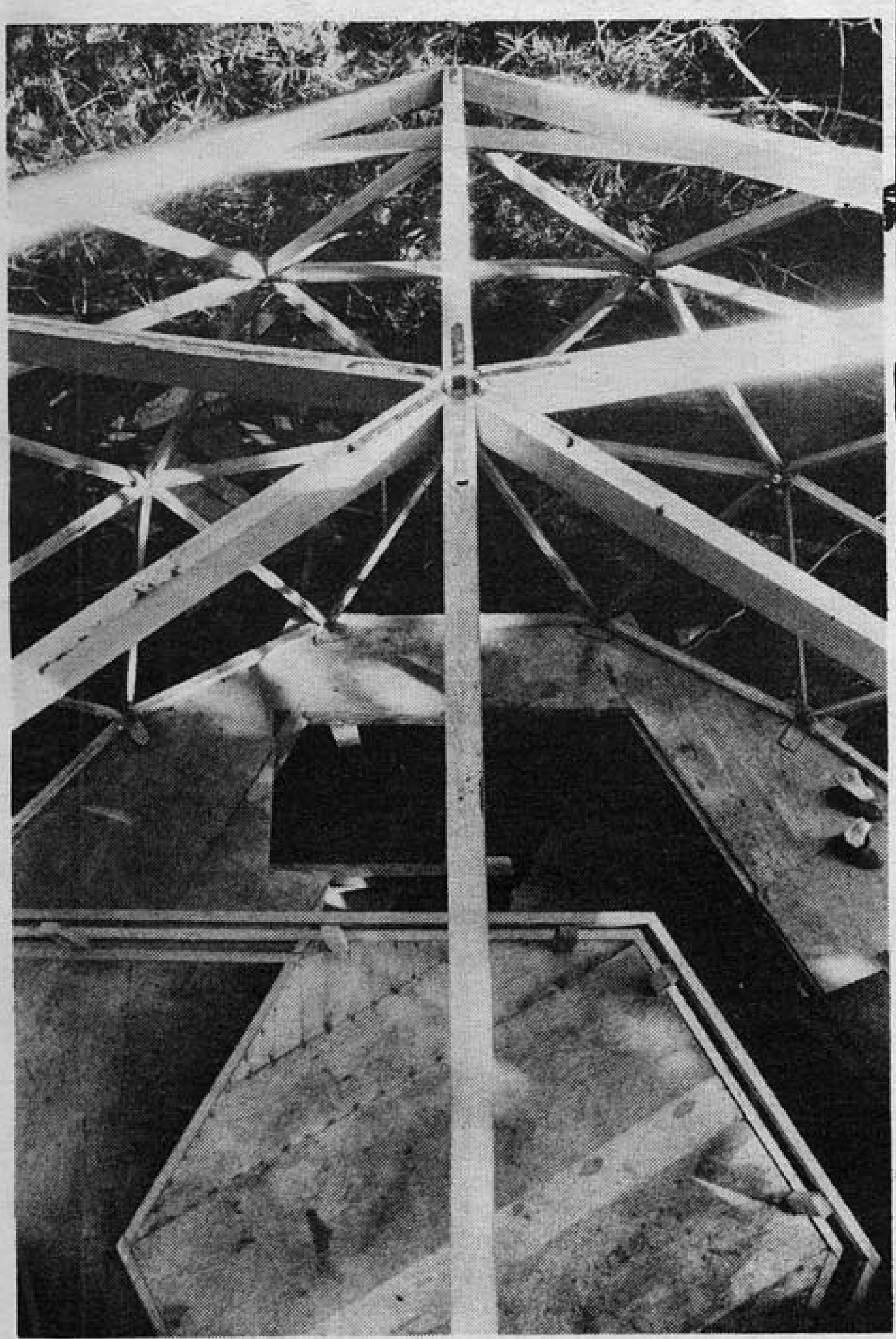
*Another method I'm trying to perfect is a wingnut-bolt assembly (to allow superfast-efficient put-up and breakdown)—hazards are: waterproofing, structure slipping under stress, form-matched spacing (probably easily solved under uniform manufacturing methods...but really a bitch for handcraft).*

*Our group is changing—people leaving for the north and the deserts, people giving up on doing anything in the shadow of the metropolis...I'd probably get my old lady and my daughter and split too—if I didn't have this other gig and desire...to make films to try changing things.*

*Herb Wright*
*Topanga, Ca.*



# 3/4 DOME



Temporary polyethelene is translucent, acrylic will be clear

Jeff Morse took the basic idea of the Pacific Dome, made refinements, and with an engineer's help, did strength tests and had plans for his dome approved in Marin County, California. The dome is very finely crafted, and most of the carpentry was done by Terry Morrison. Jeff's approach was to have the frame itself analyzed and approved; this means he can skin it with anything, since the skin is not necessary for structural strength.

3/4 Dome temporarily covered with polyethelene bag

*The idea of the ¾ dome is to enclose a big single space and yet retain the more practical workings of a conventional home. In this case the bathroom (center hex) is the only complete enclosure within the big space. The 4' high space between the ¾ deck and partial 5/8 deck allows for closets, storage, and mechanical equipment.*

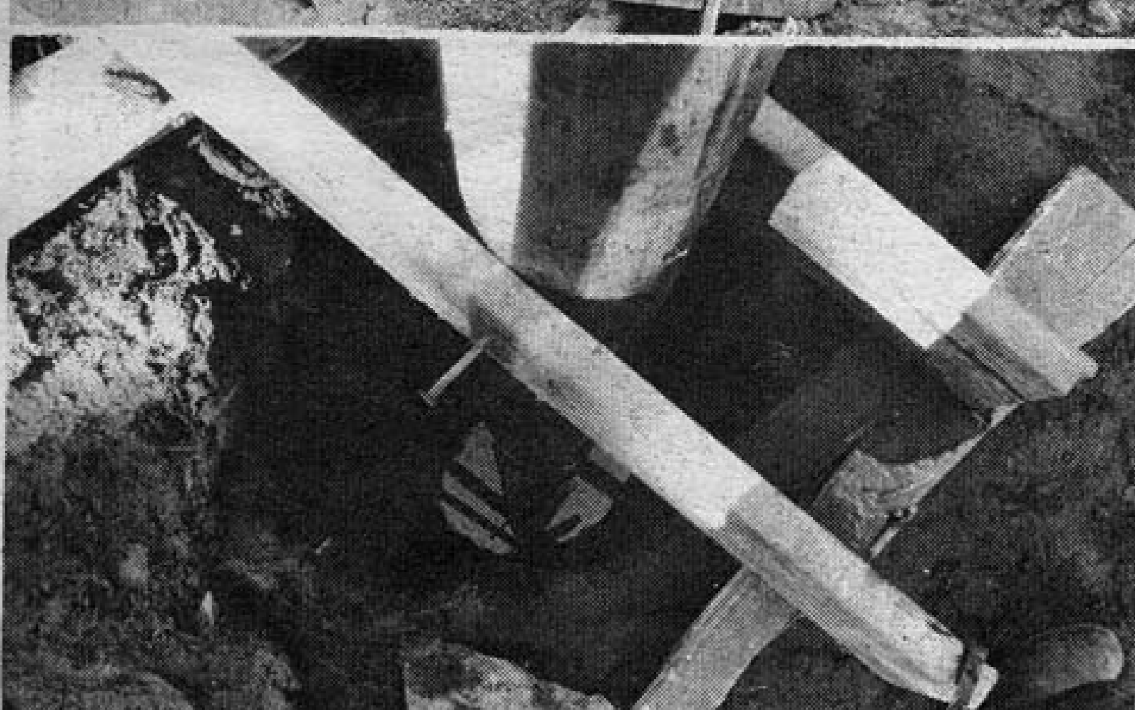
*An attempt is also being made to reduce the barrier between man and the surroundings to a minimum but still retaining a reasonably high degree of control over the environment within the skin. This is done by using a 1/8" thick transparent acrylic sheet skin with lightweight insulation panels that pop in or out of the triangulated framework as needed to block out direct sun, reduce heat loss on winter nights or gain privacy. The transparent shell idea only survives by using nature's cloak—a pine forest in this case—as a primary sun break. It is like a fern or a mushroom.*

*An important aspect of this dome is that it has been engineered and approved by building officials. We learned several things. First, that it is over-structured—partially the support system. This is the price often paid when building within the law. Second, that building officials are prepared to take structures like this seriously if they are approached seriously. We had a set of plans (working drawings) and a computerized structural analysis. The other approach is to load test the built structure provided you can vonvince them to let you build it. A serious and sincere attitude is a big help. Many areas have both building departments and planning depts. The first is concerned with whether the structure is safely habitable; the second primarily with its appearance and how it relates to its surroundings. Both are valid concerns but both can be fatal to proposed domes unless they are rather carefully considered.*

# 3/4 DOME DETAILS

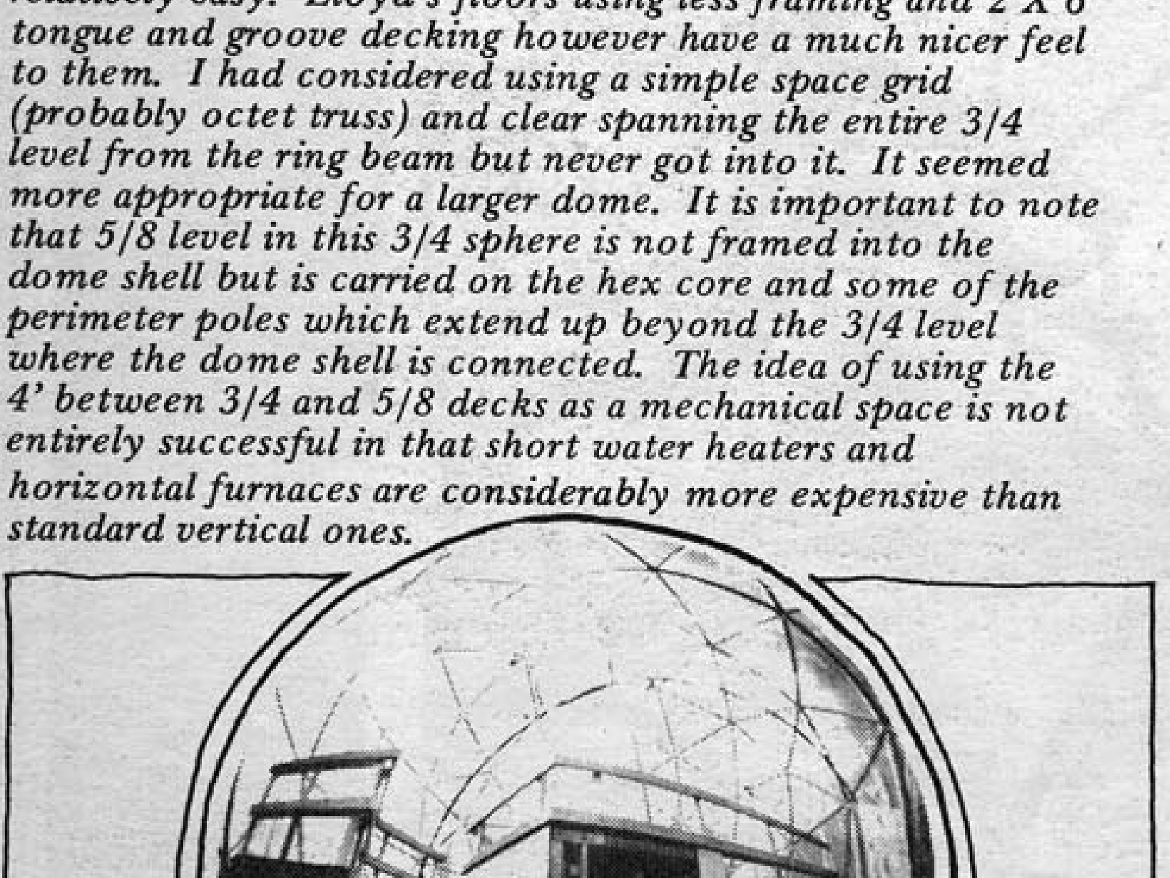
## FOUNDATION SYSTEM

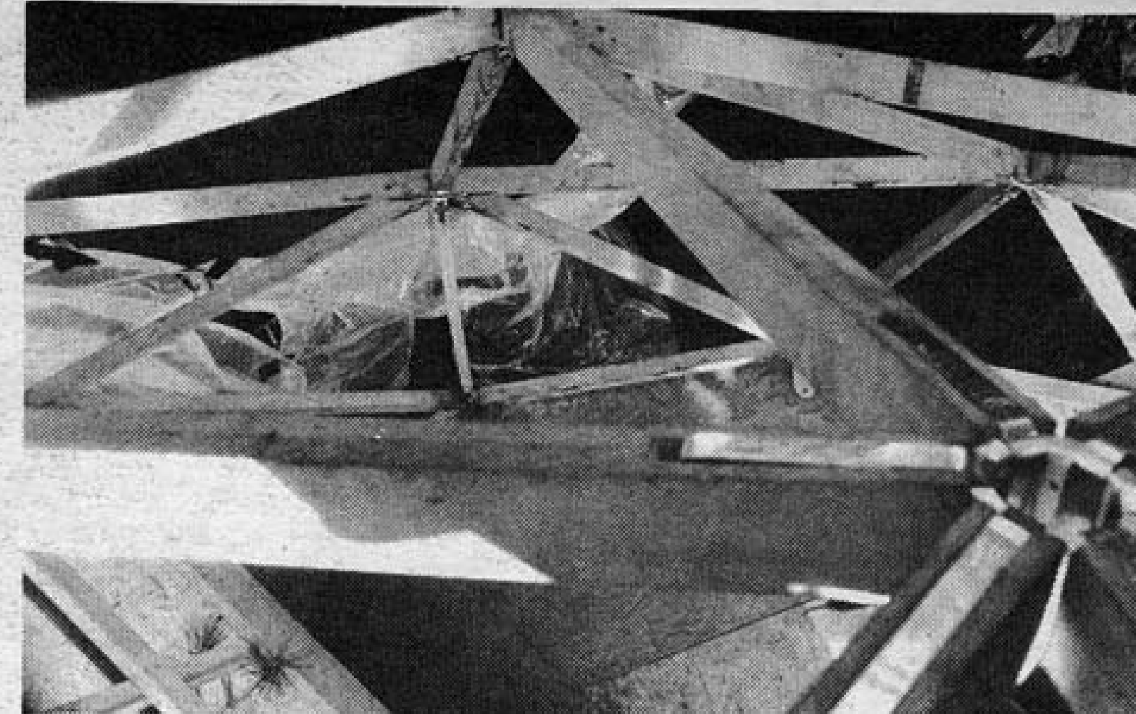
*Treated wood building poles 8" tip diameter are set in augered holes in the earth and back filled with compacted sand or concrete. The extension of the pole into the ground is a function of the type of soil and how far above ground it extends to support the dome. We went 5-7 feet down with our perimeter poles as was called for by engineering although less would have been adequate in the sandy/clay soil. Ten poles were used on the perimeter and six on the interior. The ten perimeter poles directly support ten of the fifteen vertices in the 3/4 level ring. The six interior short poles support the hexagonal shaft (bathroom) in the center. The poles were located by shooting alternating 27-degree and 45-degree angles from the dome center with a builder's transit and measuring out along these radial lines. (The radial distance is a function of the dome diameter and can be determined graphically, 10' 1" to outside of pole is what we used. The interior poles are set in the same way but using 60-degree increments. A possible economy in the support system would be to use five perimeter poles and heavier deck framing members at the 3/4 level. The poles would have to extend deeper into the earth but would probably have to be no larger since the size is determined in having enough material to work at the framing connections.*



## DECK FRAMING

*The 3/4 deck was flush framed with 3 X 8's and 2 X 8's (primarily because they were donated to us) using 12 gauge and 16 gauge clip angles and joist hangers at the junctions. The angles can be easily bent to accommodate the range of angles that are likely to occur. A ring of 3 X 8's was first set up around the perimeter connecting the perimeter poles together and setting the level, then the spans were made to the interior posts of the hex. The 5/8 level and lower level framing is conventional 2 X 6 joisting with 5/8 plywood subfloor. This has the advantages of being fast and relatively easy. Lloyd's floors using less framing and 2 X 6 tongue and groove decking however have a much nicer feel to them. I had considered using a simple space grid (probably octet truss) and clear spanning the entire 3/4 level from the ring beam but never got into it. It seemed more appropriate for a larger dome. It is important to note that 5/8 level in this 3/4 sphere is not framed into the dome shell but is carried on the hex core and some of the perimeter poles which extend up beyond the 3/4 level where the dome shell is connected. The idea of using the 4' between 3/4 and 5/8 decks as a mechanical space is not entirely successful in that short water heaters and horizontal furnaces are considerably more expensive than standard vertical ones.*

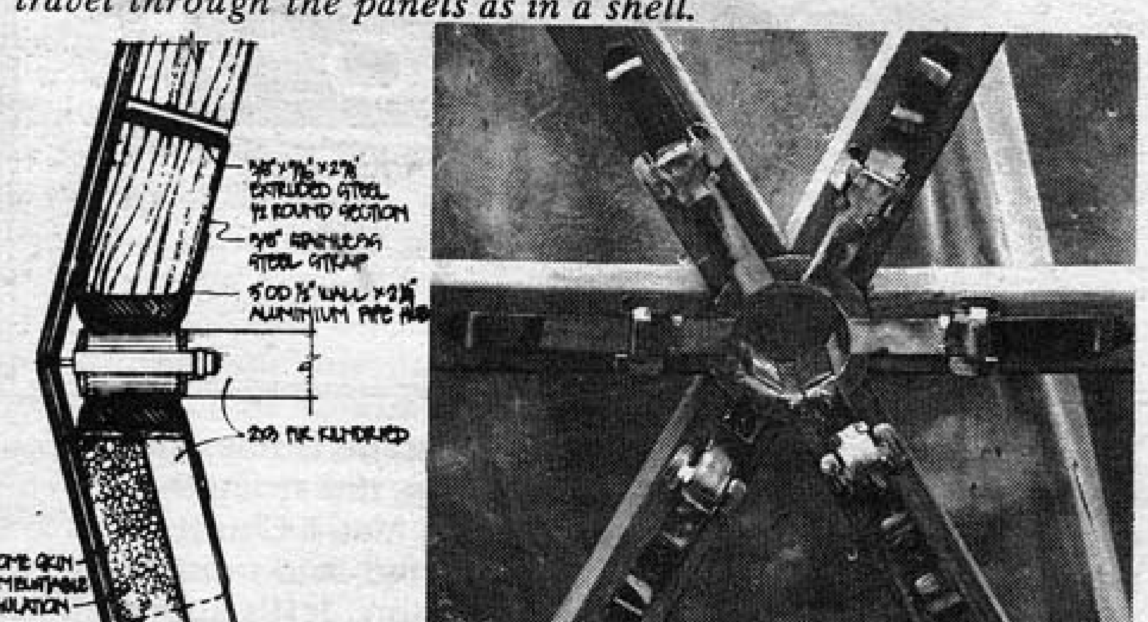




## SHELL FRAMING

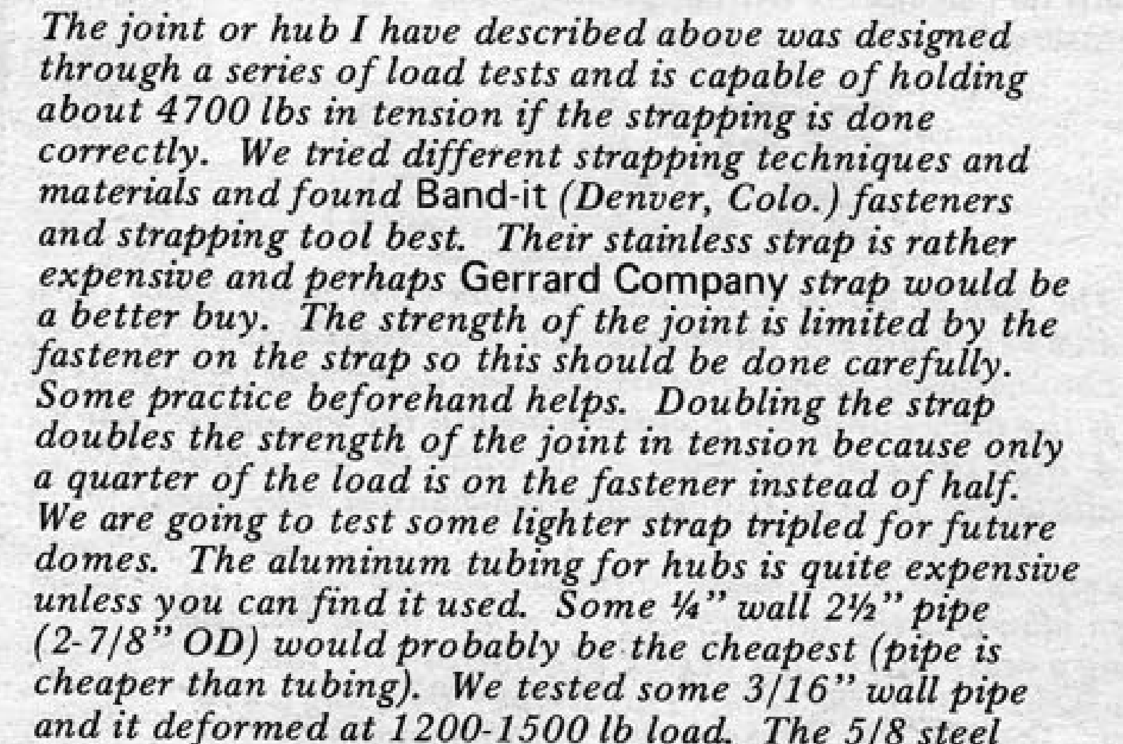
*The 24' 3/4 sphere shell is framed with 1950 lineal feet of kiln dried straight grain fir 2 X 3. The sticks were first cut to size and end cut as in the Pacific Dome. The dihedral angle (166° throughout) was then ripped on the outer edge (7° off each side) using same radial arm saw; the 5/8" holes drilled 4 inches from each end using a drill press and the ends were slotted to receive the 5/8" stainless steel strapping. The slotting was done with a dado blade on the radial saw. The ends of the struts were then sanded concave using a 3" sanding drum on a lather (or drill press) so the struts would bear directly against the 3" hub. 1/8" was added on each end of the strut to allow for this sanding operation. These mechanical operations on the struts went rather quickly and seemed to be worthwhile in avoiding later problems of joinery. The other components of the frame are: 66 hubs cut in 2¼" lengths from a 16' length of 3" OD ½" wall aluminum tubing, 1500 ft of 5/8" X .030 stainless steel strapping with 420 fasteners, 420 2¼" X 5/8" half round bars cut from extruded steel half round sections with bolt cutters. These steel half rounds are inserted into the 5/8 holes and distribute the tensile loads from the strapping to the strut without crushing the wood fibers. The stainless steel strap is run twice through the fastener (doubled) at each connection.*

*It must be noted that this structure is designed as a framework not as a shell in other words the frame distributes wind loads, live loads and the like from any point on the structure to the ground and does not depend on the panels for stiffening effect. The panels can be simply infill and have only to distribute external loads placed on them to their local edge members. This allows the use of acrylic sheet and similar non-structural panel materials. If one were using structural panels such as plywood the hub design could be much lighter or could be eliminated altogether since the stresses could then travel through the panels as in a shell.*

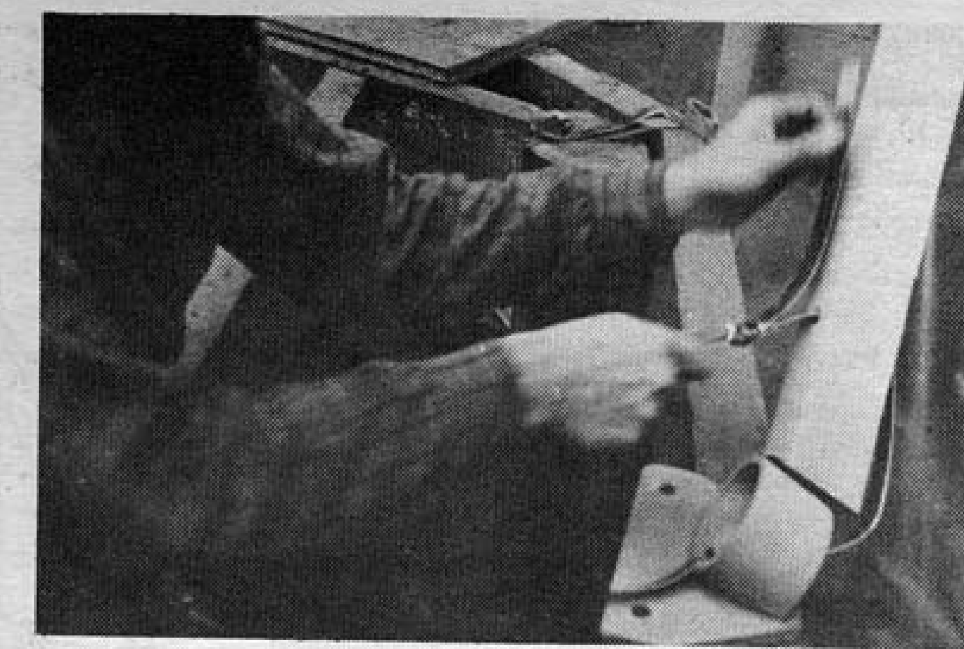


HUB SECTION ③

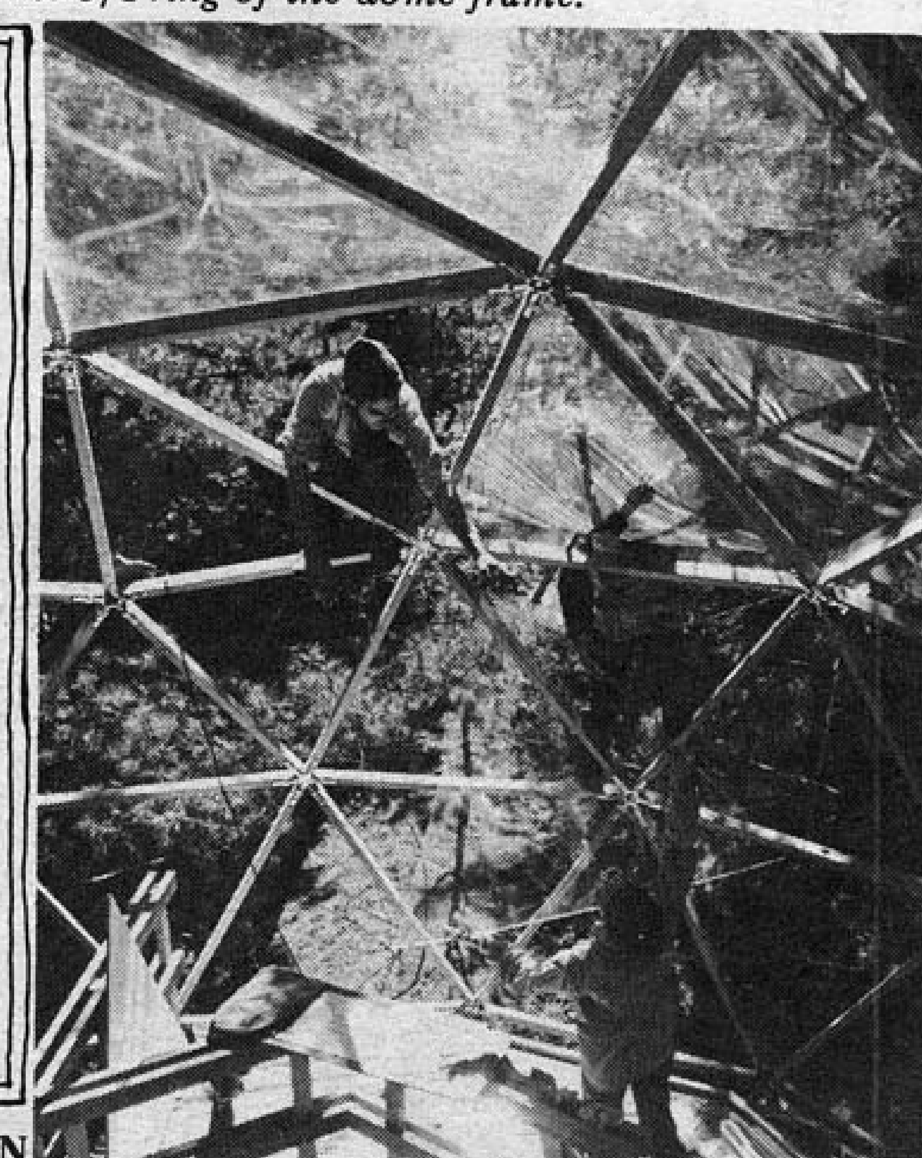
*The joint or hub I have described above was designed through a series of load tests and is capable of holding about 4700 lbs in tension if the strapping is done correctly. We tried different strapping techniques and materials and found* Band-it *(Denver, Colo.) fasteners and strapping tool best. Their stainless strap is rather expensive and perhaps* Gerrard Company *strap would be a better buy. The strength of the joint is limited by the fastener on the strap so this should be done carefully. Some practice beforehand helps. Doubling the strap doubles the strength of the joint in tension because only a quarter of the load is on the fastener instead of half. We are going to test some lighter strap tripled for future domes. The aluminum tubing for hubs is quite expensive unless you can find it used. Some ¼" wall 2½" pipe (2-7/8" OD) would probably be the cheapest (pipe is cheaper than tubing). We tested some 3/16" wall pipe and it deformed at 1200-1500 lb load. The 5/8 steel half rounds are cheap and worthwhile in that they keep the joint (and thus the frame) taut by not allowing deformation of the drilled hole in the strut (available at* U.S. Steel in S.F.)



*The frame was built from the top down. A 1½" pipe thru the center hub guyed to the trees around was used to hold the frame as the struts were strapped in place. Positioning an entire course loosely and then tightening it down was the method that evolved because once a strut is tightened it is not easily moved.*



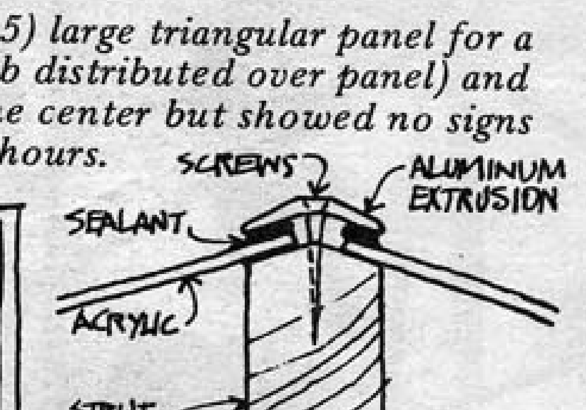
*When completed, the frame was connected to the 3/4 deck using 10 steel half hubs welded to ¼" steel plates and bolted to the foundation poles below. The advantages of building it from the top down are: you don't need scaffolding and there is no problem of closure at the top because of inaccuracy in placing the 10 support hubs. This is important with a tight framing system like this. Even with our graphic calculations we were a couple of inches off in the diameter of our support system. This can be compensated for to some extent by slotting the plate on which the support hubs sit to allow them to move in or out to take up any difference in diameter between the support ring and the 3/4 ring of the dome frame.*



## THE SKIN

*We'll skin the first dome next weekend so a lot of this is theory. We're using .150 clear acrylic sheet (like plexiglas) for the large triangle and .125 clear for the small. The .150 material we got on a 51" wide roll (2400 lbs) 450 ft long, from a southern California plastics Co.—Swedlow Inc. We designed a cutting table with hingeable arm in which runs a skil saw. Both triangle types can be cut by adjusting the angle of the arm. Cutting diamonds (2 triangles) and then flipping them and cutting them into triangles seemed to be the best procedure—that way we didn't have to change the angle for any given triangle type. A veneer or plywood blade on the saw works well. The advantage of the roll over sheets is of course that you need not waste material or splice panels. Fortunately 51" is a standard width which works well for the 24' sphere. The disadvantage is handling; it takes a small army to move the roll around. A general problem with acrylic over other materials is the cost. The square foot wholesale price of 1/8" is 59¢. Retail is about 90¢. Warehouse clearance sales occur occasionally and we were lucky enough to hit one.*

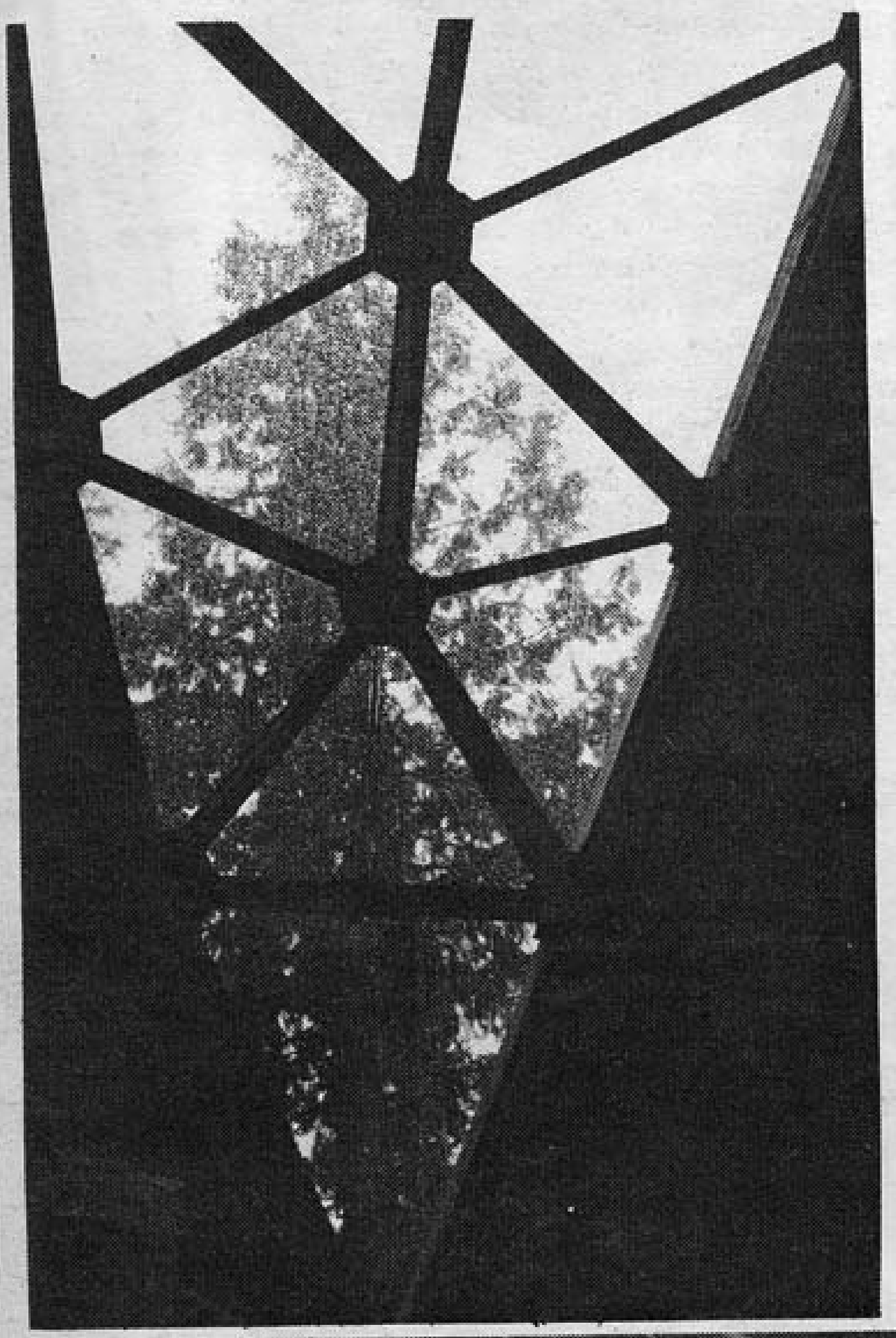
*We load tested an 1/8" (.125) large triangular panel for a 20 lb/sq ft wind load (220 lb distributed over panel) and it deflected about 1½" in the center but showed no signs of giving way even after 24 hours.*

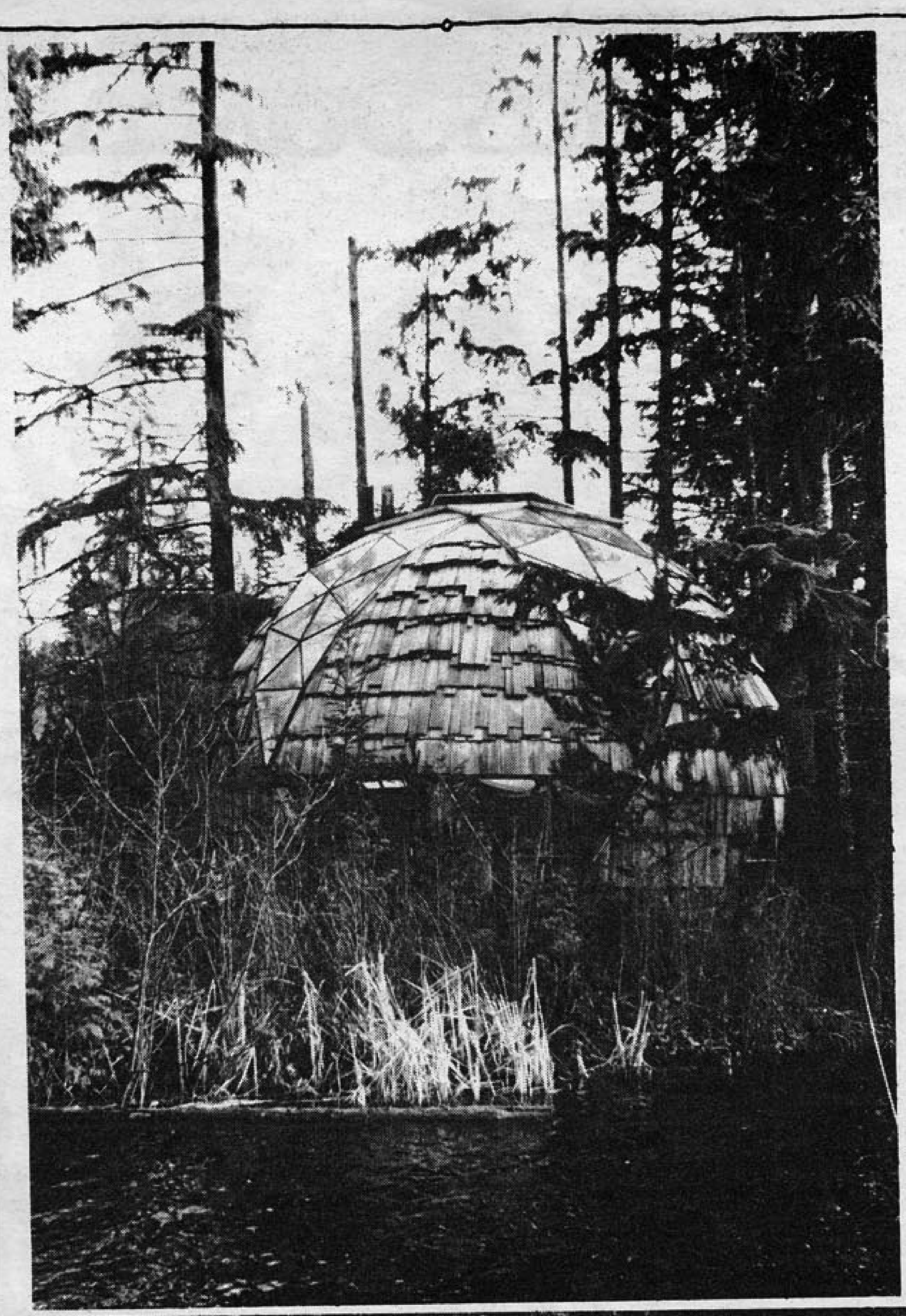



*The panels will be held in place by an extruded aluminum angle section (166°—dihedral) that runs along the strut and clamps the two adjacent acrylic panels between the aluminum and the acrylic to keep the water out. We have tested three sealants for adhesion to aluminum and acrylic: 3M Weatherban 101 (Hypalon), 3M Weatherban 202 (Polysulfide) and GE silicone. The silicone is most resilient but all three seem to adhere well to the materials. Keep in mind these were small tests and give only one aspect of performance necessary to keep the structure watertight.*

*For ventilation we're going to try one operable triangle high (hinged at the top pent) and three operable low (between 3/8 and 5/8 rings). I think this will be plenty but we have no experience yet. The other aspect of the skin, the insulation/privacy aspect (as opposed to the weather seal), is dealt with by panels of ½" rigid polyurethane foam skinned on both sides with heavy white vinyl-impregnated paper (milk carton material). The panels will be press-fitted into the triangulated framework and can be taken in and out as the days and seasons vary. They are stored between the 3/4 and 5/8 decks. ½" of polyurethane foam is deemed adequate insulation on the west coast by heating people we talked to.*

If you have bldg. code requirements, a 9 sheet set of dome plans & a discrete member struct. analysis are available for sale from Jeff Morse, Box 207, Cotati, CA. 94928.





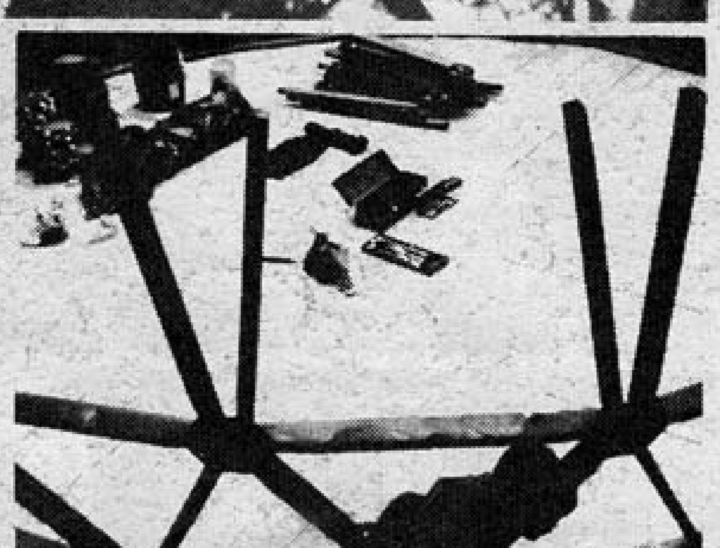
# SHAKE DOME

**A few days before we finished putting together this book, we received these pictures and letter from Jim Anderson, describing his cedar shake dome in Washington. Jim was able to achieve a round exterior surface by nailing bats on a relatively high frequency dome.**

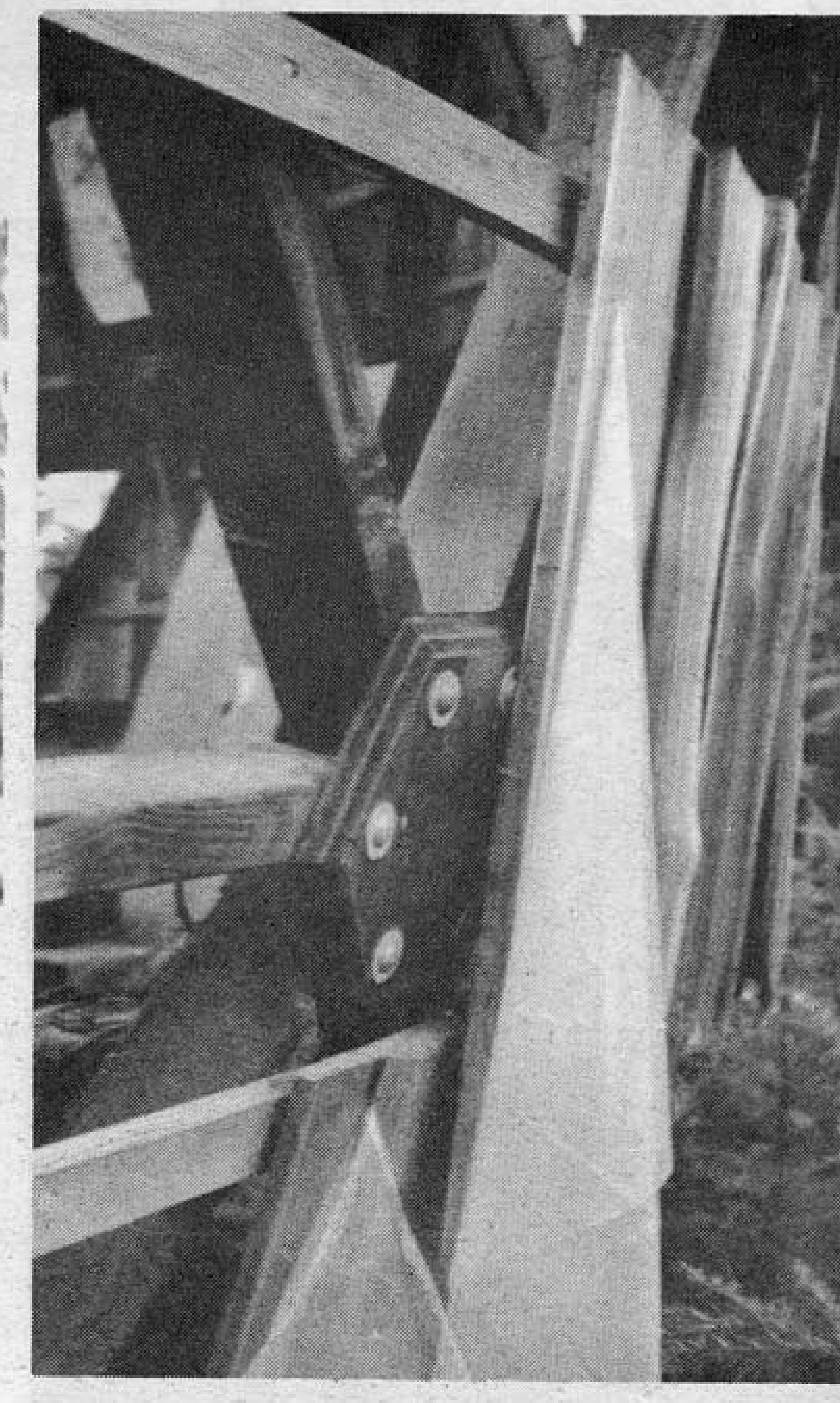
*Split cedar shakes and boards are an art form with ancient roots in the Pacific Northwest. They were used by local Indians for their long houses. Shakes are organic, renewable, bio-degradable and funky. Each one is unique and they even smell fine.*

*This particular dome was "jointly" created by three manually illiterate former intellectuals (with a help from our friends).*

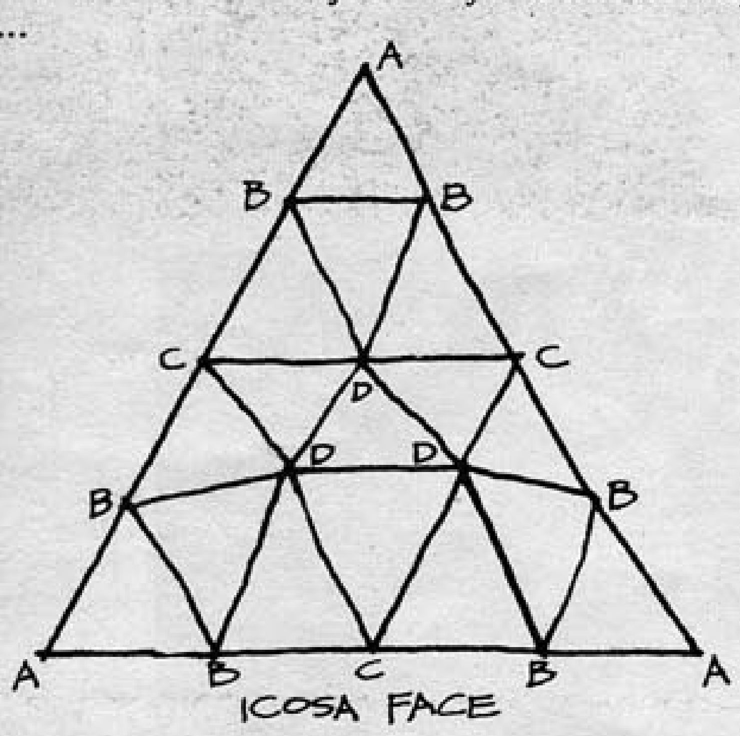
# SHAKE DOME



Frame is 2 X 4 members bolted to 3/4" ply gusset plates. Bolts were ½ usual price through a salvage yard. Works fine with dry wood; friction prevents pivoting. Green wood shrinks and requires retightening bolts.



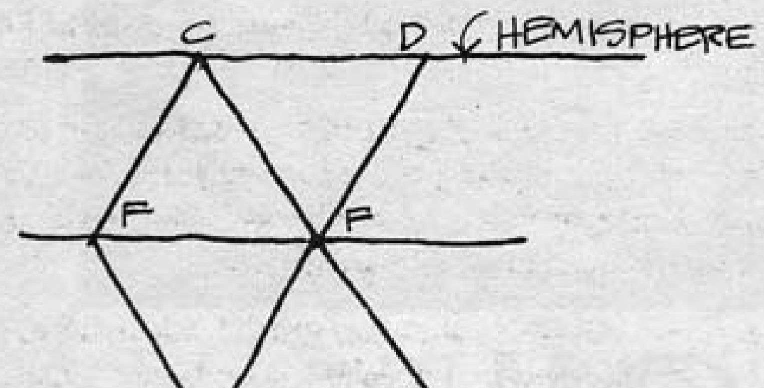
Structure is 4v icosa-alternate hemisphere +30° spherical truss = 2/3 sphere, 12 ft radius, 18 ft high. The hemisphere is unusual in being broken down asymmetrically—has more flowing appearance because the triangular array is more varied. Here are the chord factors for both hemisphere and truss...




4v Icosa Alternate—Asymmetrical

| | Chord Factor | End Bevel |
|---|---|---|
| CB: | 0.3294 | 9.5° |
| DD: | 0.3249 | 9.5° |
| CD: | 0.3129 | 9° |
| BD: | 0.3091 | 9° |
| BB: | 0.2596 | 7.5° |
| AB: | 0.2215 | 6.5° |

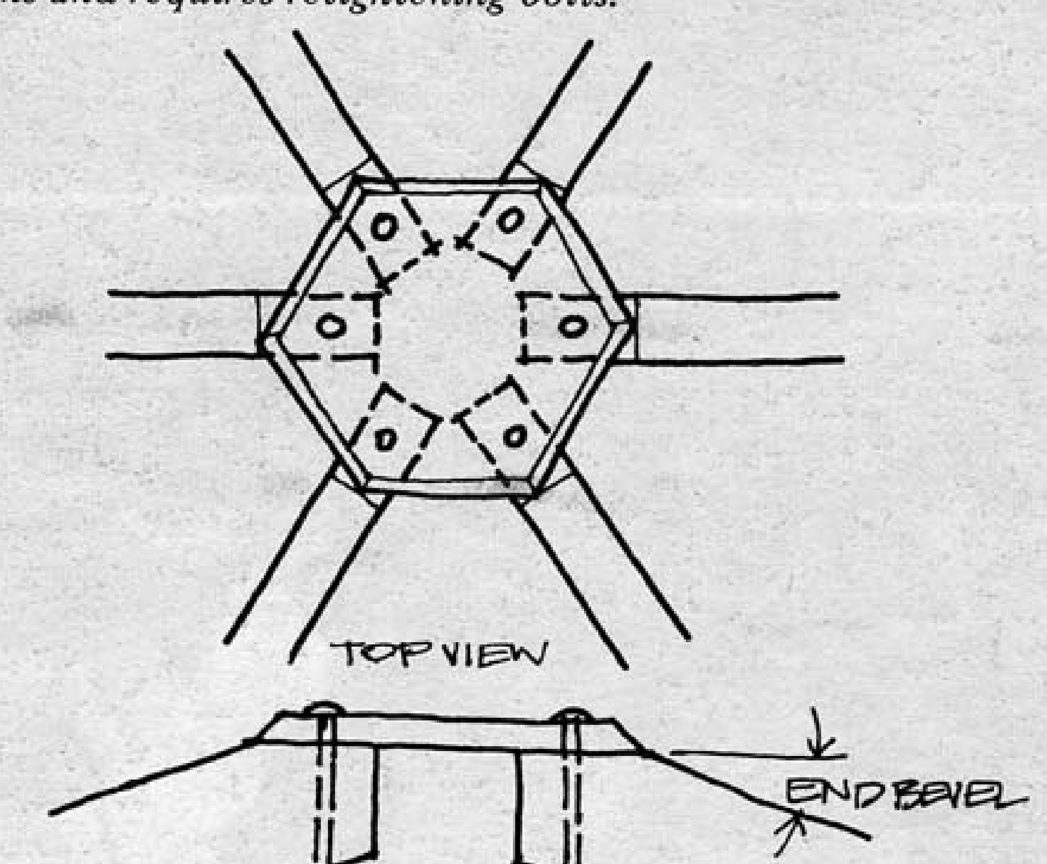
Chord factor x radius = Member Length




30° Spherical
(4v hemisphere to 2/3 sphere)

| | Chord Factor | End Bevel |
|---|---|---|
| CD: | 0.313 | 9° |
| CF=FF=FG: | 0.301 | 9° |
| GG: | 0.270 | 9° * |

*20 GG members form the bottom ring. They are compound beveled at 9° and at 60° to lie horizontal.

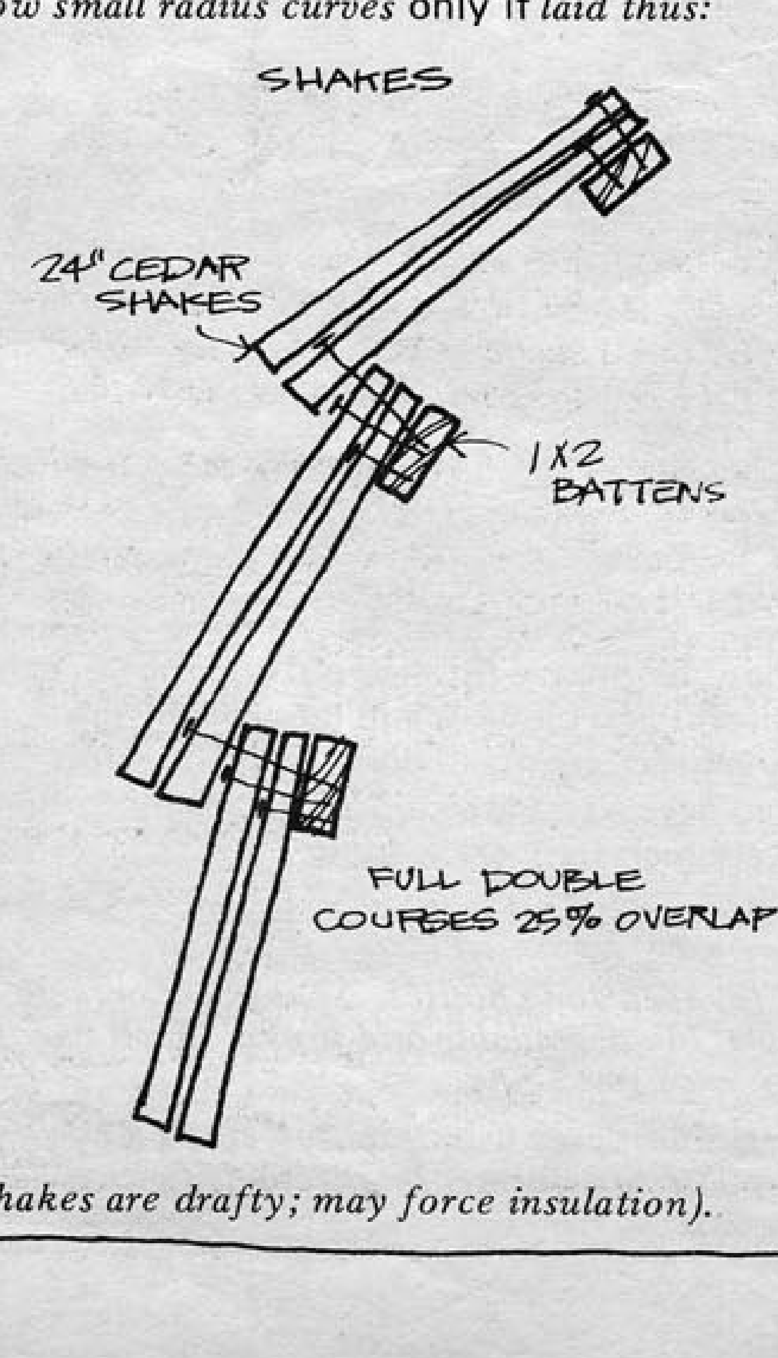



Whole structure uses 1000 bd ft or 1500 lin ft. Cost us $60 after a lot of shopping around; normally around $130.

We've cut out members using both a skill saw and a radial arm saw. Radial is easier, but a good jig and a skill saw works fine. All components were pre-stained using 1 cup of non-fiber roofing tar dissolved in a quart of paint thinner. Stain color is variable from tan to black by varying tar content. It is cheap, preservative, and accents the frames.

Skin is hand split cedar shake and 10 mil vinyl. We got enough bolts (cedar blocks 24" long) to make all our shakes for $30 plus scrounging. 10 mil vinyl is from Sears ($65).

1 X 2 battens nailed bent around the dome provide nailing for the shakes. Shakes are inherently linear and therefore will follow small radius curves only if laid thus:




(Shakes are drafty; may force insulation).

It rains all the time here, so our big overhead skylights are usually a moving flow pattern. Vinyl is laid over a space grid frame—1 X 6 perimeter frame nailed to the sides of members and notched for gusset plates; 1 X 2 cross frames spanning from perimeter frame to mid-light gussets in the same pattern as members. The perimeter frame sticks out 4" past members so skylights can be sealed to shakes via aluminum flashing.

All vinyl seams and edges, both in lower windows and skylights, are sealed with Scotch 5230 wood adhesive. Vinyl is slick and many sealants either won't stick or melt the vinyl. 5230 sticks tenaciously to anything, even wet wood (but not to wet vinyl). Doesn't harm the vinyl. Sears 4" polyethylene tape is instant repair for vinyl.

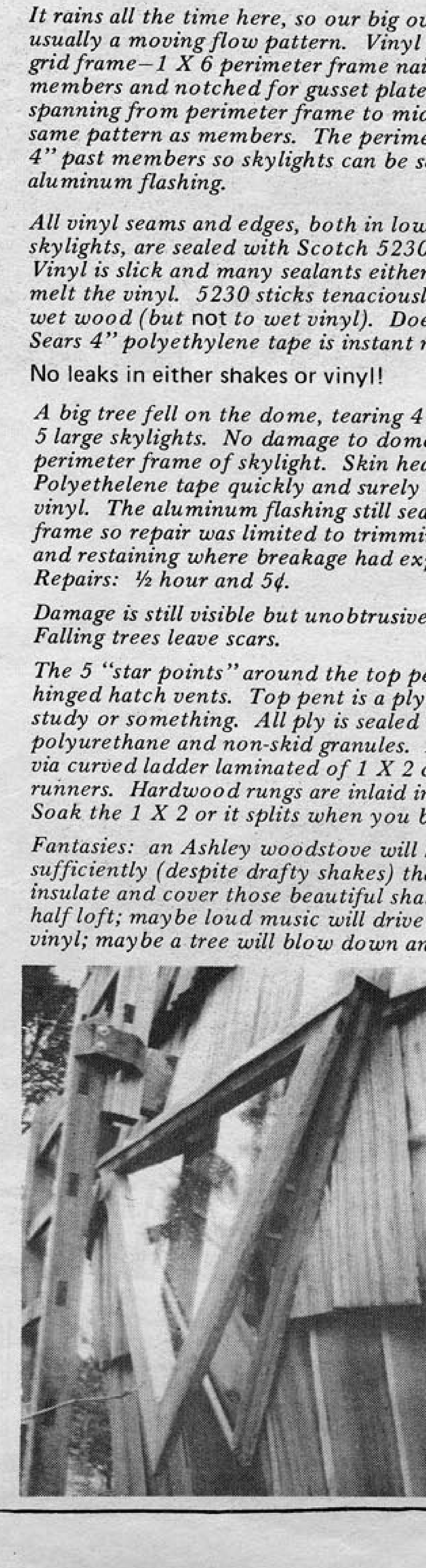
No leaks in either shakes or vinyl!

A big tree fell on the dome, tearing 4 small holes in 3 of the 5 large skylights. No damage to dome frame; crushed one perimeter frame of skylight. Skin healed nicely. Polyethelene tape quickly and surely sealed the rips in the vinyl. The aluminum flashing still sealed its crushed frame so repair was limited to trimming off sharp splinters and restaining where breakage had exposed raw wood. Repairs: ½ hour and 5¢.

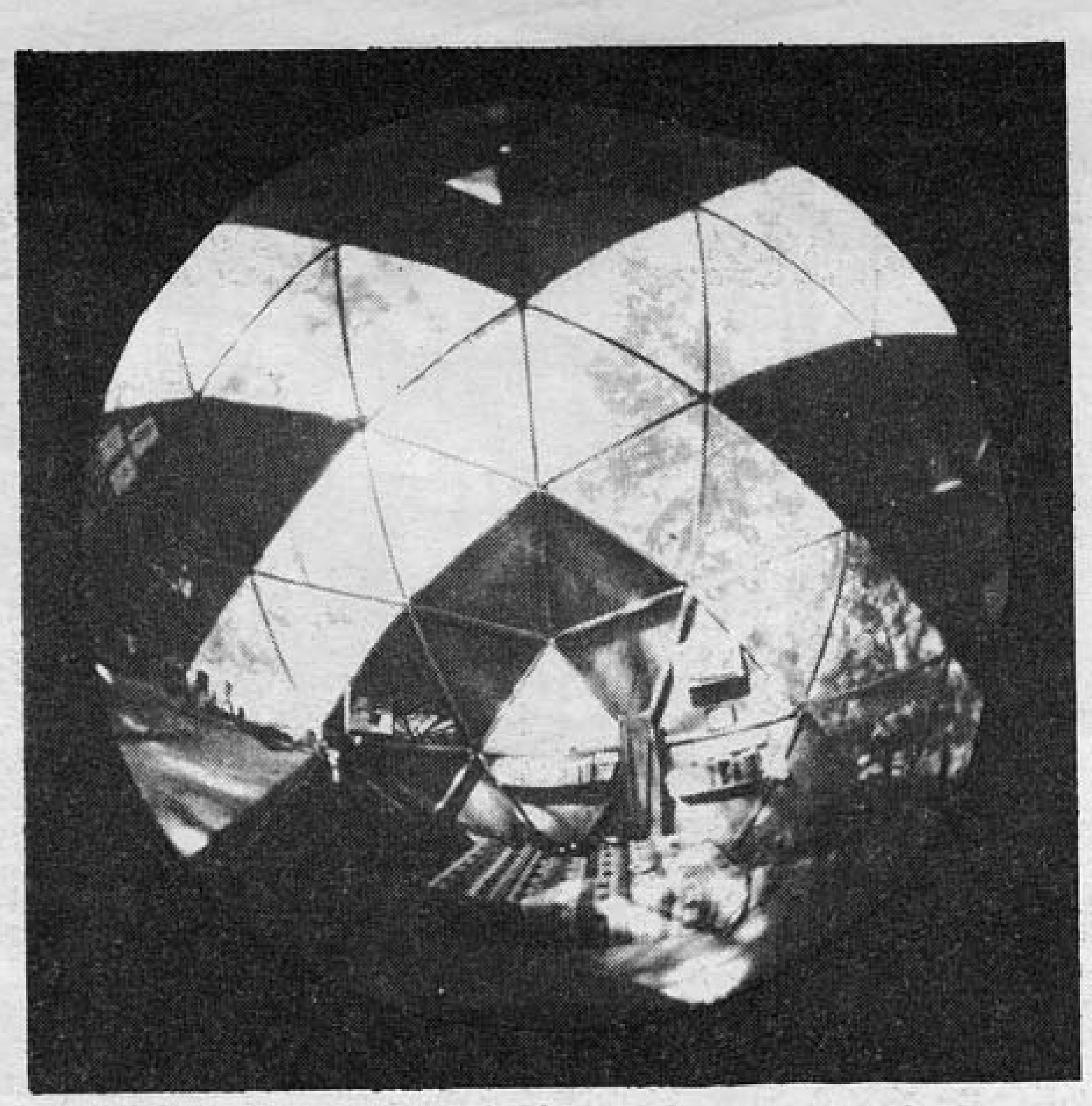
Damage is still visible but unobtrusive and waterproof. Falling trees leave scars.

The 5 "star points" around the top pent are ply/cedar hinged hatch vents. Top pent is a ply platform for nature study or something. All ply is sealed with marine polyurethane and non-skid granules. Access to platform via curved ladder laminated of 1 X 2 cedar to make 2 X 4 runners. Hardwood rungs are inlaid in the third lamination. Soak the 1 X 2 or it splits when you bend it.

Fantasies: an Ashley woodstove will heat the dome sufficiently (despite drafty shakes) that we won't have to insulate and cover those beautiful shakes; an S-shaped half loft; maybe loud music will drive the water on the vinyl; maybe a tree will blow down and not hit the dome.

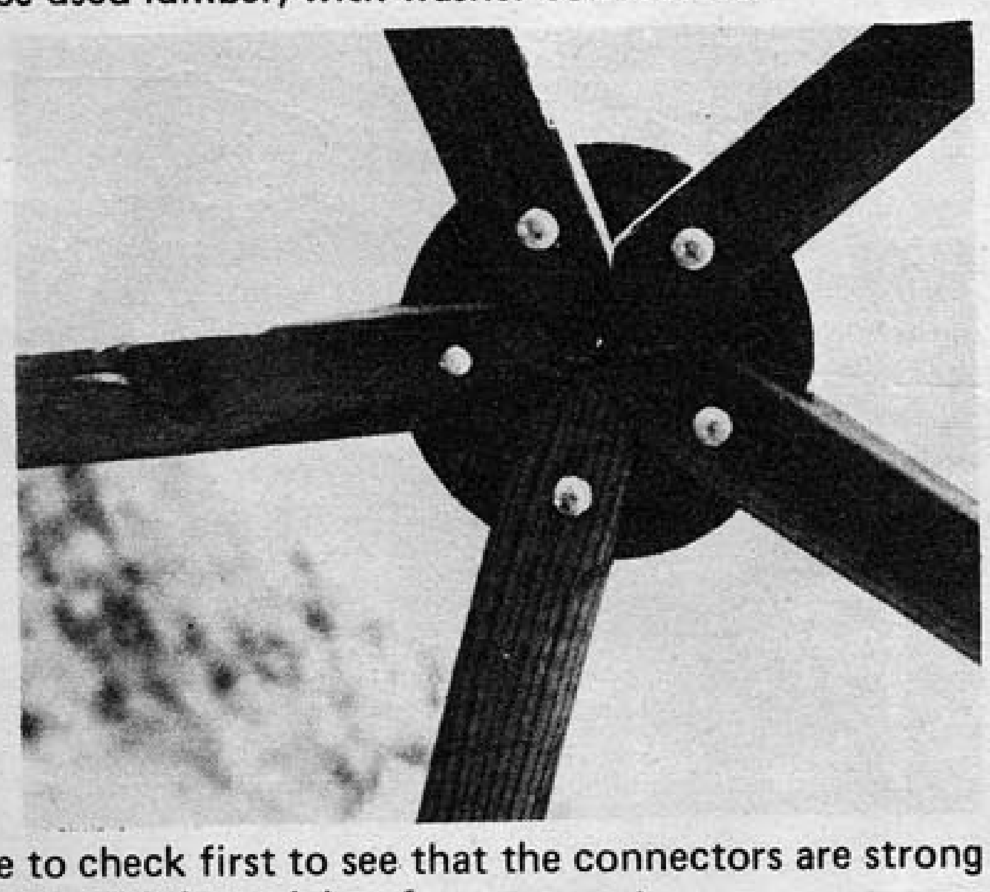


Jim Anderson.
John Groff



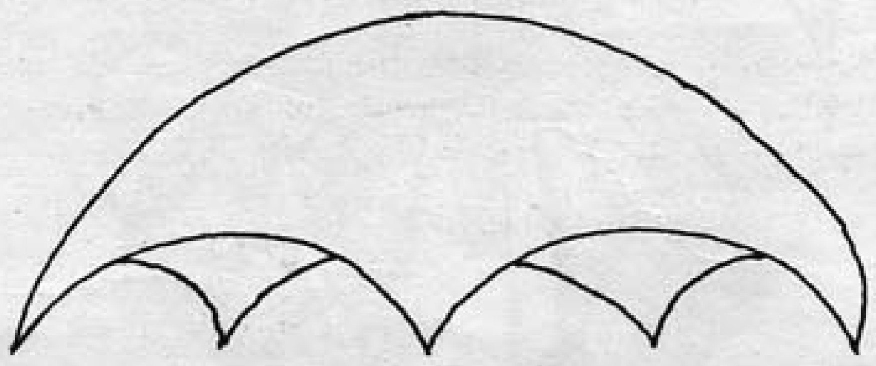
Lately I've been thinking about a ferro cement dome on a wooden frame. I've always liked the idea of a monolithic shell, no separate components to piece together, no leaks.

It will be used lumber, with washer connectors.



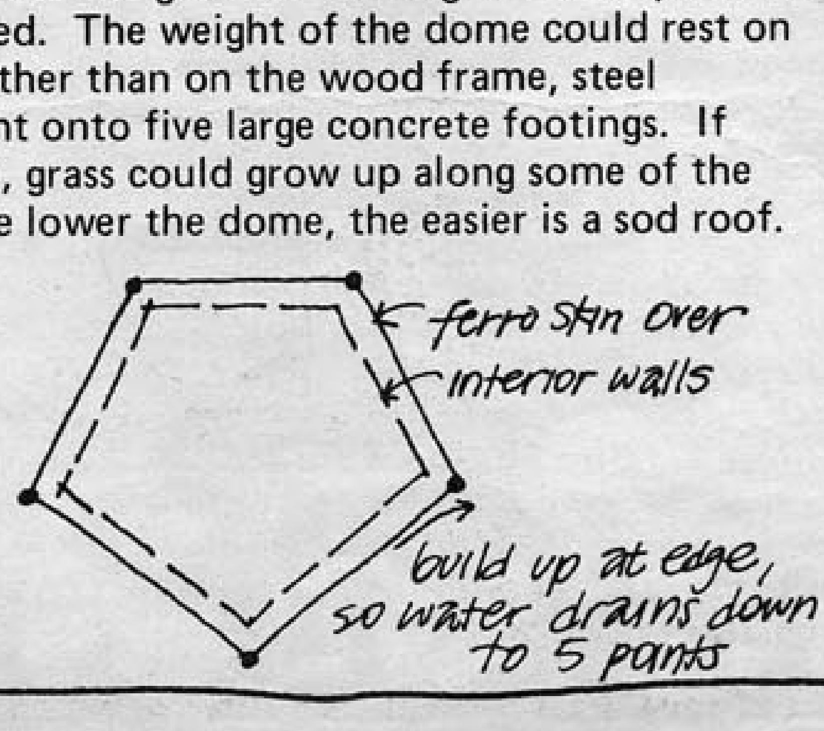
I'll have to check first to see that the connectors are strong enough to hold the weight of wet cement.

This summer when I put together the cardboard model of the aluminum triacon dome, I noticed that with the first ten diamonds together it formed a pentagonal flower shape, touching the ground at five points with arches in between. It suggested a low dome, sculptural ferro cement flowing into the ground at five points.



We've lived for two years now in a dome without easy access to *outside.* To be able to move in and out more freely, to be able to have large sections open I'd build walls inside the shell, using the ferro skin as an umbrella.

The arches would be curved, would need extra steel to carry weight down to the ground. An engineer's help would probably be needed. The weight of the dome could rest on the five points, rather than on the wood frame, steel carrying the weight onto five large concrete footings. If it's strong enough, grass could grow up along some of the touch points. The lower the dome, the easier is a sod roof.



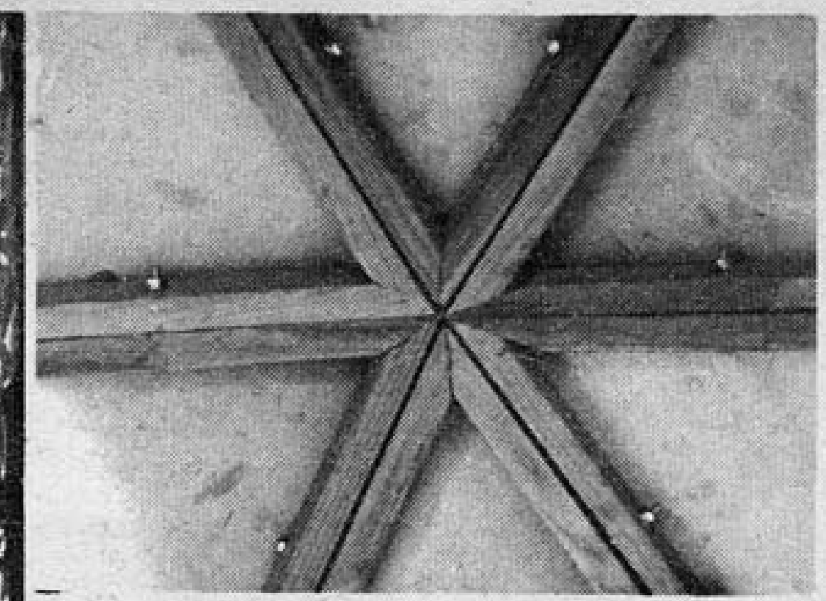

A low frequency dome, such as the Jensens built, has acute axial angles that resist external load. As the frequency for a given diameter increases, the danger of popping in increases. Thus, I'll have to check this out carefully, maybe some posts would have to be used for propping inside while wet concrete sets. After seeing the Cedar Shake Dome (p. 53) I decided to try to make the ferro dome round; not sure how to do this yet, perhaps the same method of batts over frame.

The walls can be built of old lumber, used doors and windows, could have sliding doors on tracks, or shoji screens. Water would run off, there would be no problem of putting doors and vents in a dome skin.

Any of the five walls could open out into a garden, or woods. Glass or plexiglas skylights, or colored glass patterns in the skin.

Insulation would be between struts, leaving them exposed— could be rigid foam held in with small nails, or fiberglass insulation, with burlap stapled in over it. You wouldn't see concrete from inside.

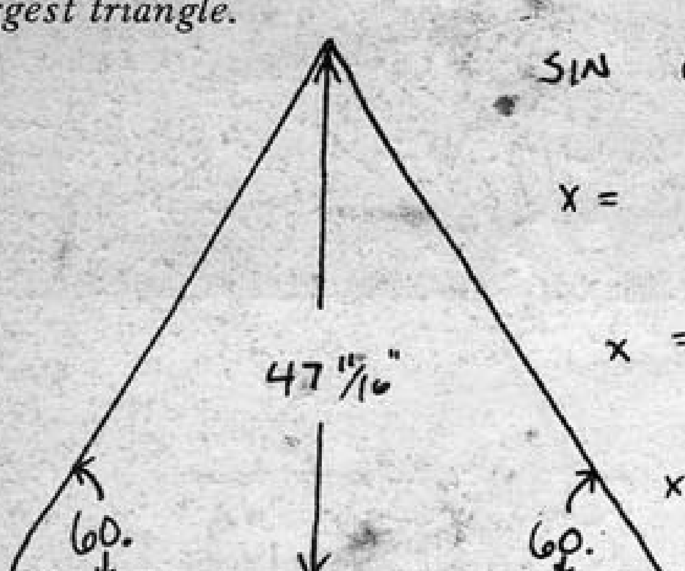
Floor might be sawdust-cement as described in a 30 year old government publication on floors for chicken houses, or if a wood floor, it should be kept as low to the ground as possible.



# Sheet
## METAL DOME

*On this dome sheet metal triangles were nailed to a wood frame with edges overlapping so that each joint worked like a shingle. This way, rain has no cracks to stand in, and should flow to the ground.*

*The triangles were cut out of 26 gauge galvanized steel that came in sheets, 47 11/16" wide. Therefore the maximum size triangle can have that width for its altitude. This was on a 3-frequency dome, so we looked up the face angles and did a little trigonometry to find the longest edge of the largest triangle.*




$$\sin 60.7^\circ = \frac{47\tfrac{11}{16}''}{x}$$

$$x = \frac{47\tfrac{11}{16}''}{\sin 60.7^\circ}$$

$$x = \frac{47.68750''}{.87207}$$

$$x = 54.68''$$ LONGEST EDGE

*Then we were able to find the radius which was needed to figure out the rest of the edge lengths, for the large and small triangles.*

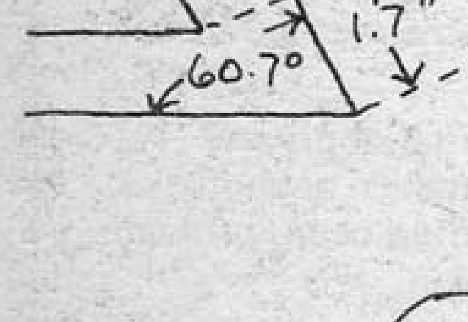
LONGEST EDGE = .4124 × RADIUS

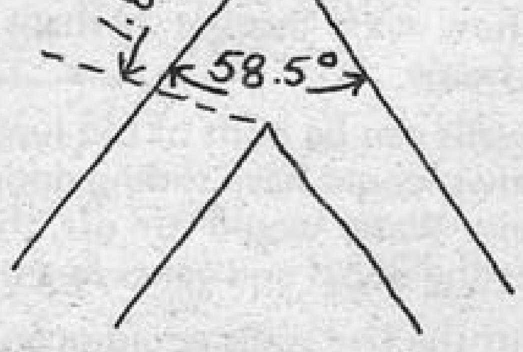
$54.68'' = .4124 \times$ RADIUS

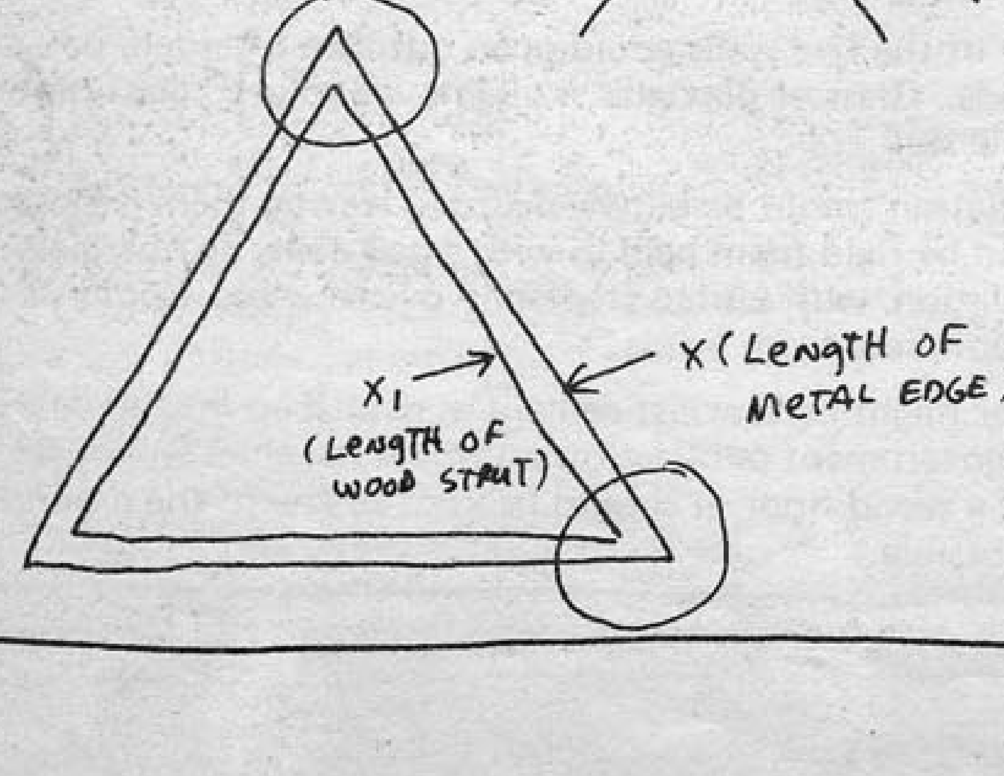
$\frac{54.68''}{.4124}$ = RADIUS

$132.59''$ = RADIUS

*The frame was computed using a smaller radius, so that all the triangles would have an inch overlap.*



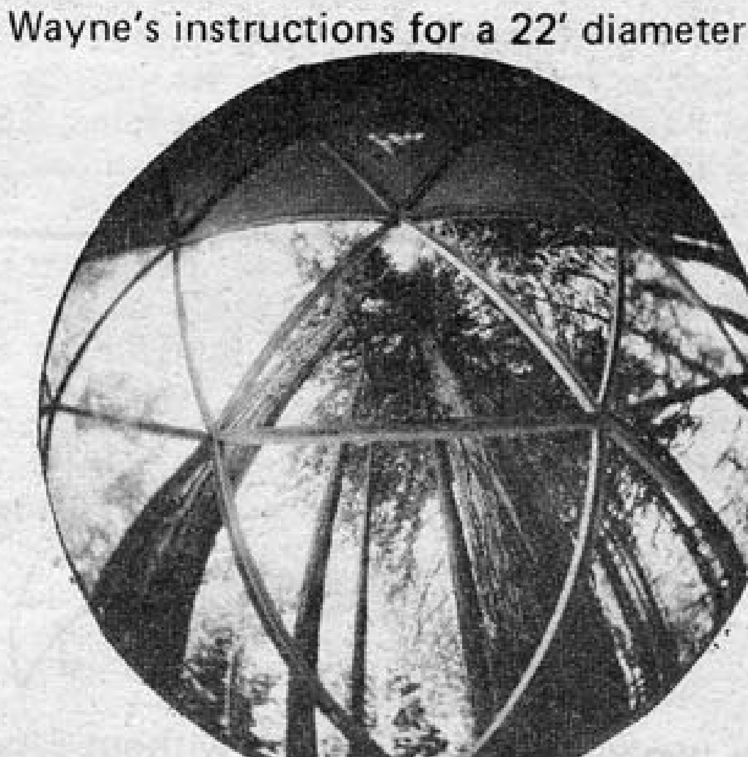




Wayne Cartwright has built four sheet metal domes since *Domebook One.* Sheet metal is cheap, and Wayne shingled the triangles, upper over lower to shed water. Three of the domes were with strapped hubs, a fourth was built like a sun dome. Regular galvanized steel will not take a coat of paint. Certain grades, however, with trade names such as *Jet Coat, Ready Coat, Paint Grip, Galvaneel,* or *Wiped Coat* are specially processed for paint application. Sheet metal is about the cheapest skin material you can find, about 10¢ per sq ft from Reliance Sheet Metal in Berkeley (Duraply plywood is about 30¢ per sq ft). Two of Wayne's domes were sprayed with polyurethane foam inside; if this isn't done there might be problems of condensation and drips in cold climates.

If you're interested in using metal for dome skins, there's a a dowdy magazine called *Metal Building Review*/Box 1255/ South Bend, Indiana 46624 – $4.00 per year.

Here are Wayne's instructions for a 22' diameter dome.



PLACITAS, N. MEX.

*Saturday afternoon, Luke, Bob, Lane and I are nailing cartops on domes. It's hot and there are a lot of visitors at the site. The shingles are heavy but the work is good as you maneuver a big piece of tin onto your head, balance it with one hand, use the other hand to steady your way up the ladder, pass the shingle to whoever is sitting on a cross piece of your frame and then wiggle, crawl your way up next to him and nail it on. All edges that will be overlapped get punched first with a 20 penny spike, then nailed with an 8 penny nail. All exposed edges get an aluminum nail with a neoprene gasket to waterproof the hole. College kids, architectural students come out to help, people from town come out to ask questions standing below necks craning upwards. Who designed these things? Over and over, the same questions. Bill collectors come out and repossess my bus.*

Steve Katona

*To find the radius of the frame, we needed to know the length of the longest strut ($X_1$):*

$X_1 = x - 1.7'' - 1.8''$

$X_1 = 54.68 - 3.5''$

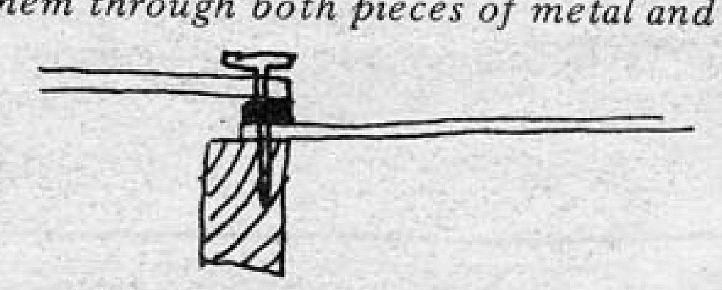
$X_1 = 51.18$

*And since:*

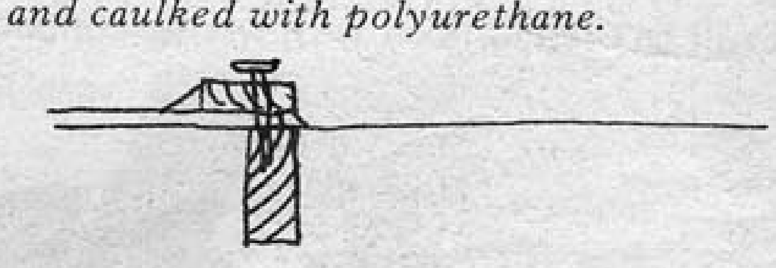
RADIUS × CHORD FACTOR (.4124) = STRUT LENGTH 51.18

$$\text{RADIUS OF FRAME} = \frac{51.18}{.4124} = 121.67''$$

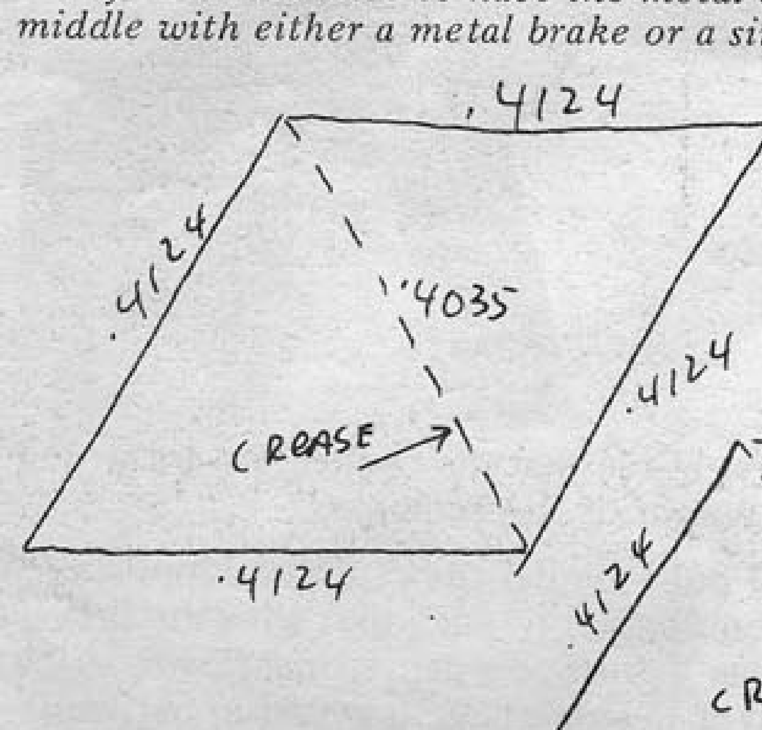
*Between the two overlapped edges we put 1 inch wide vinyl foam tape (from Harold Price Co., Richmond, Ca.) as an added protection for nail holes, strong winds and vertical joints. The tape comes in rolls and is sticky on one side. We pulled it out and stuck in onto whatever edge was slipped under the overlap. We used 1¼" roofing nails, and drove them through both pieces of metal and the tape.*

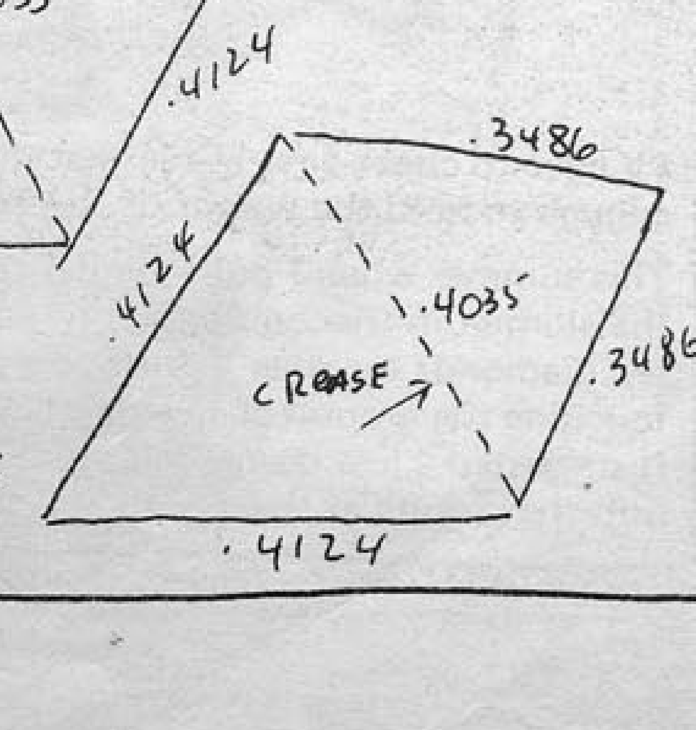


*We started at the zenith and went down, leaving the overlaps un-nailed until the underlaps (with tape) were slipped into place. Vinyl windows were stapled onto the struts, battened, and caulked with polyurethane.*

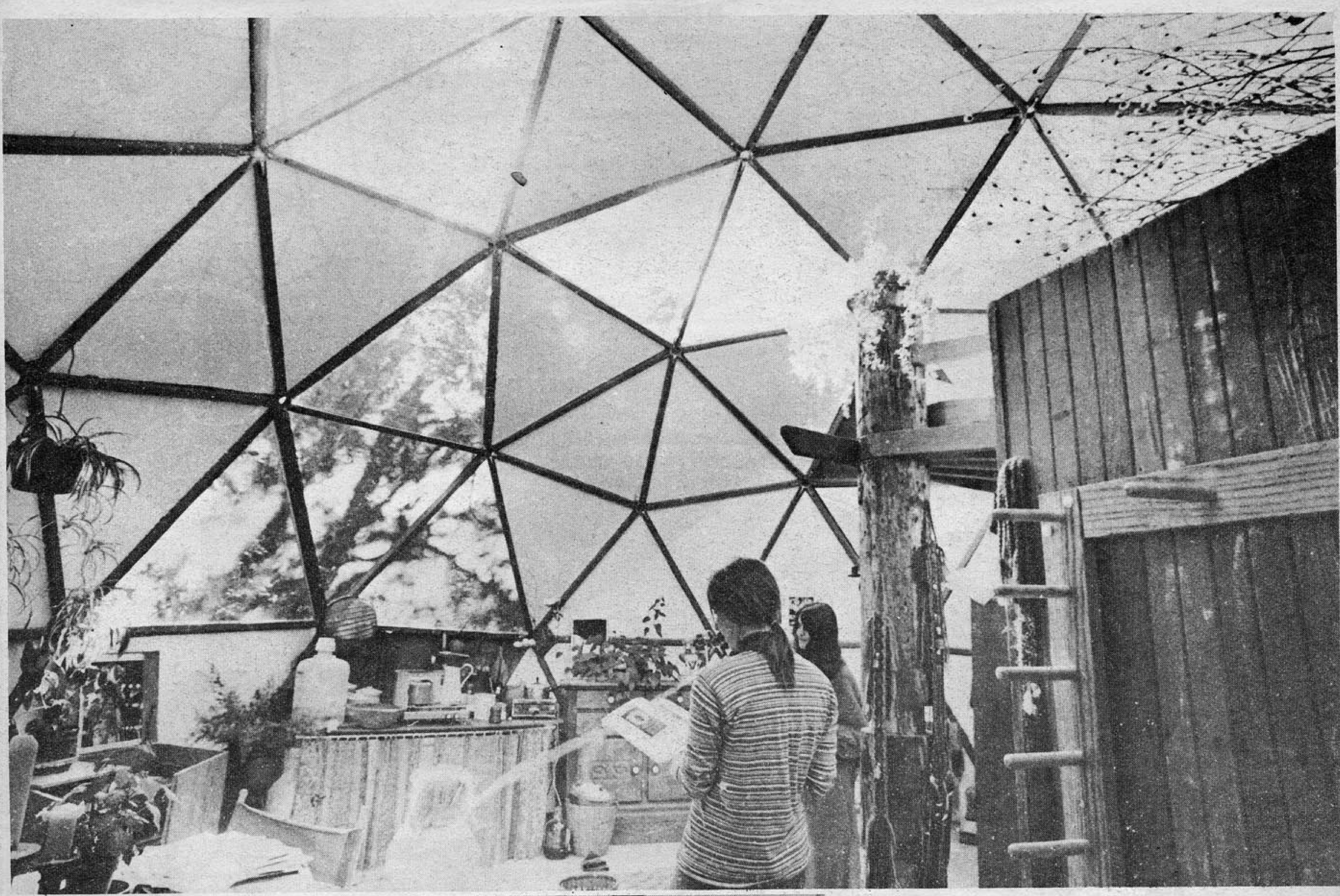


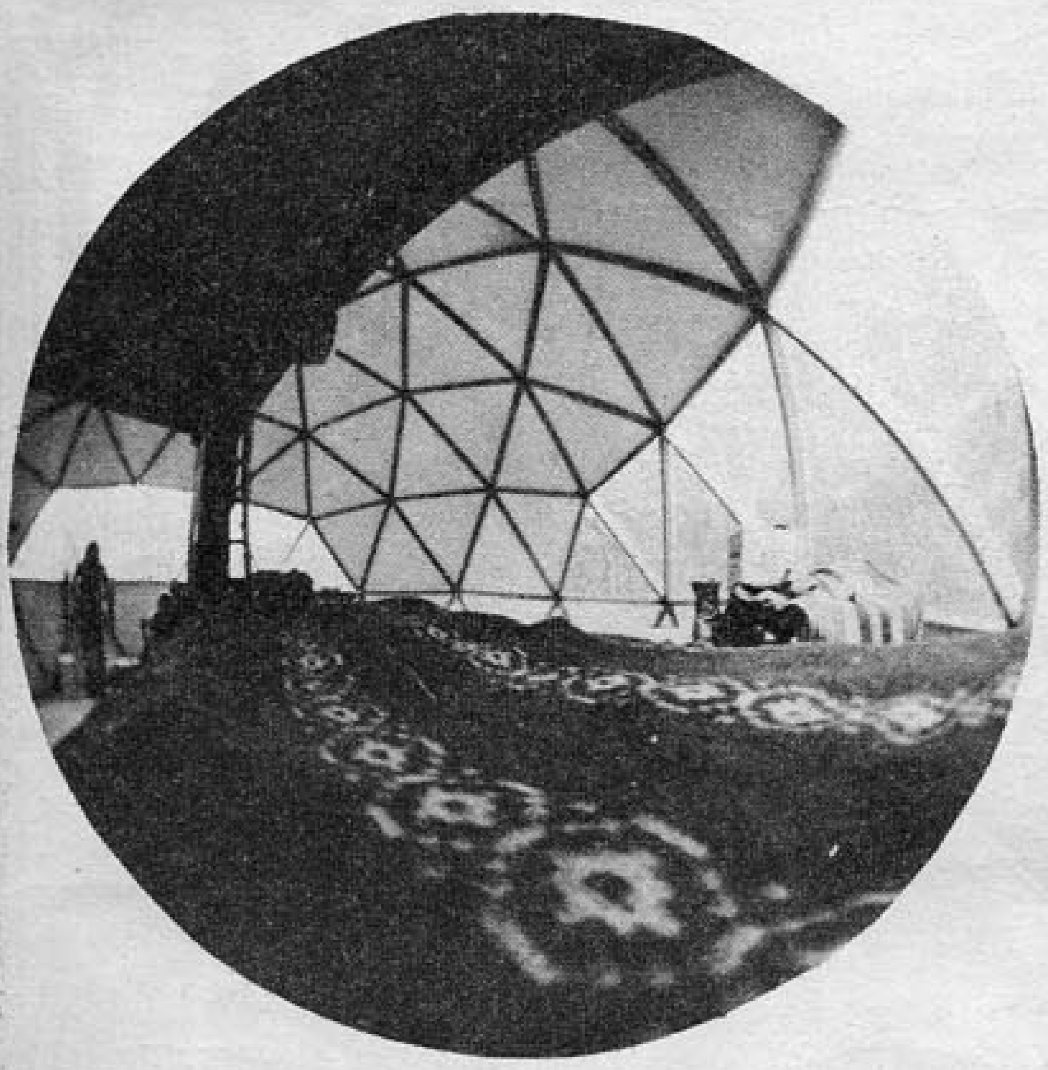
*Instead of cutting the metal into triangles, you could cut it up into diamonds, and eliminate some of the joints. You would also cut down on the cutting. However, it means that you would have to have the metal creased across the middle with either a metal brake or a similar invention.*

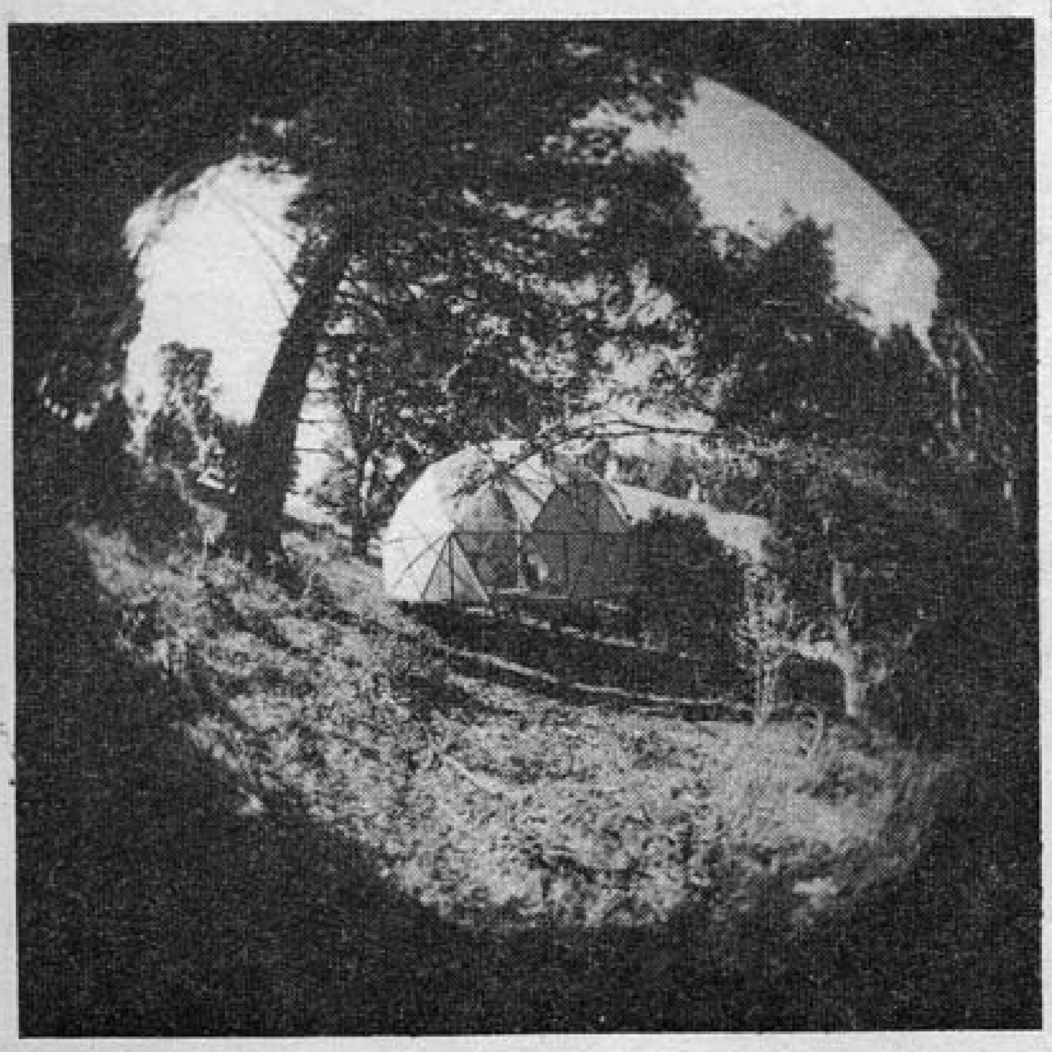


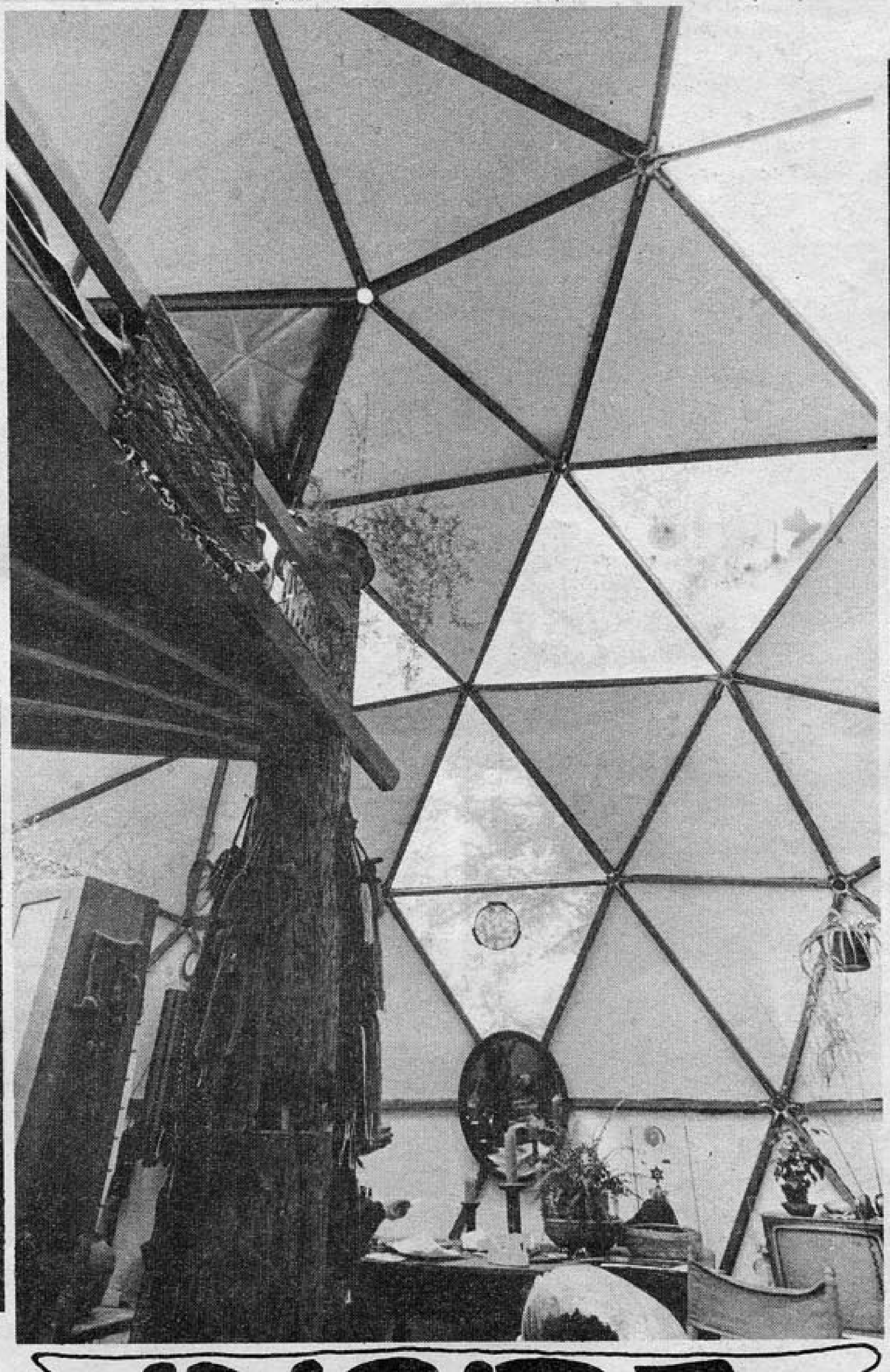



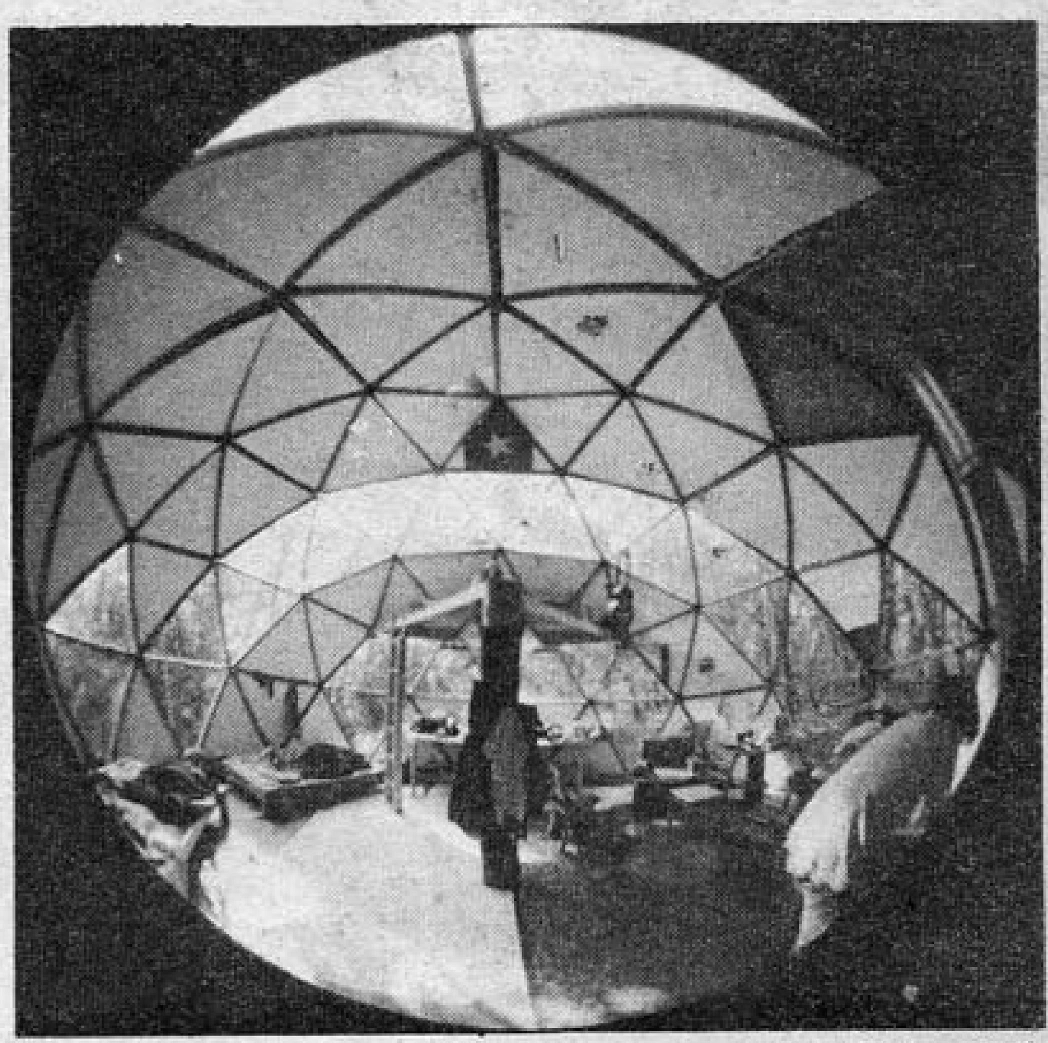

Wayne Cartwright
1000 Alba Rd.
Ben Lomond, CA

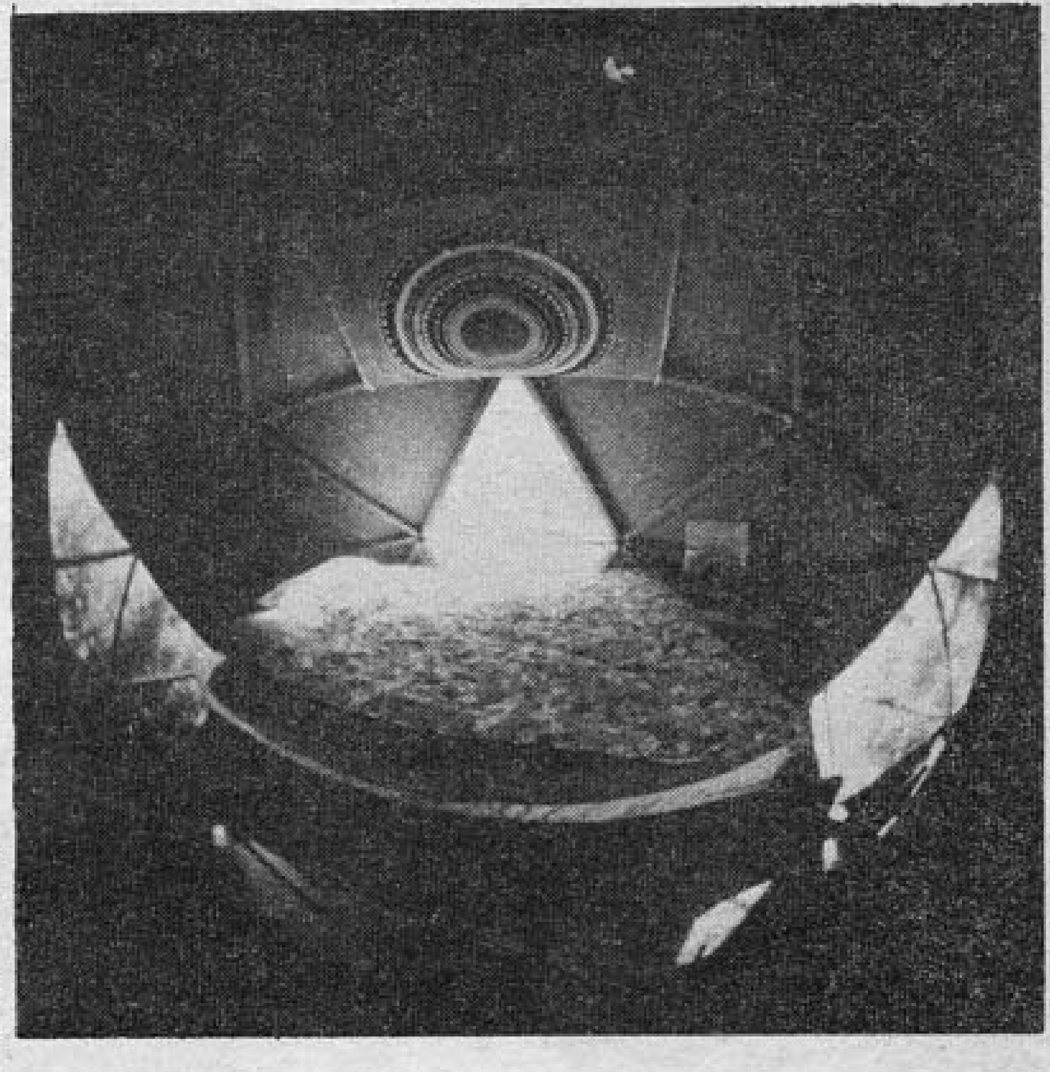






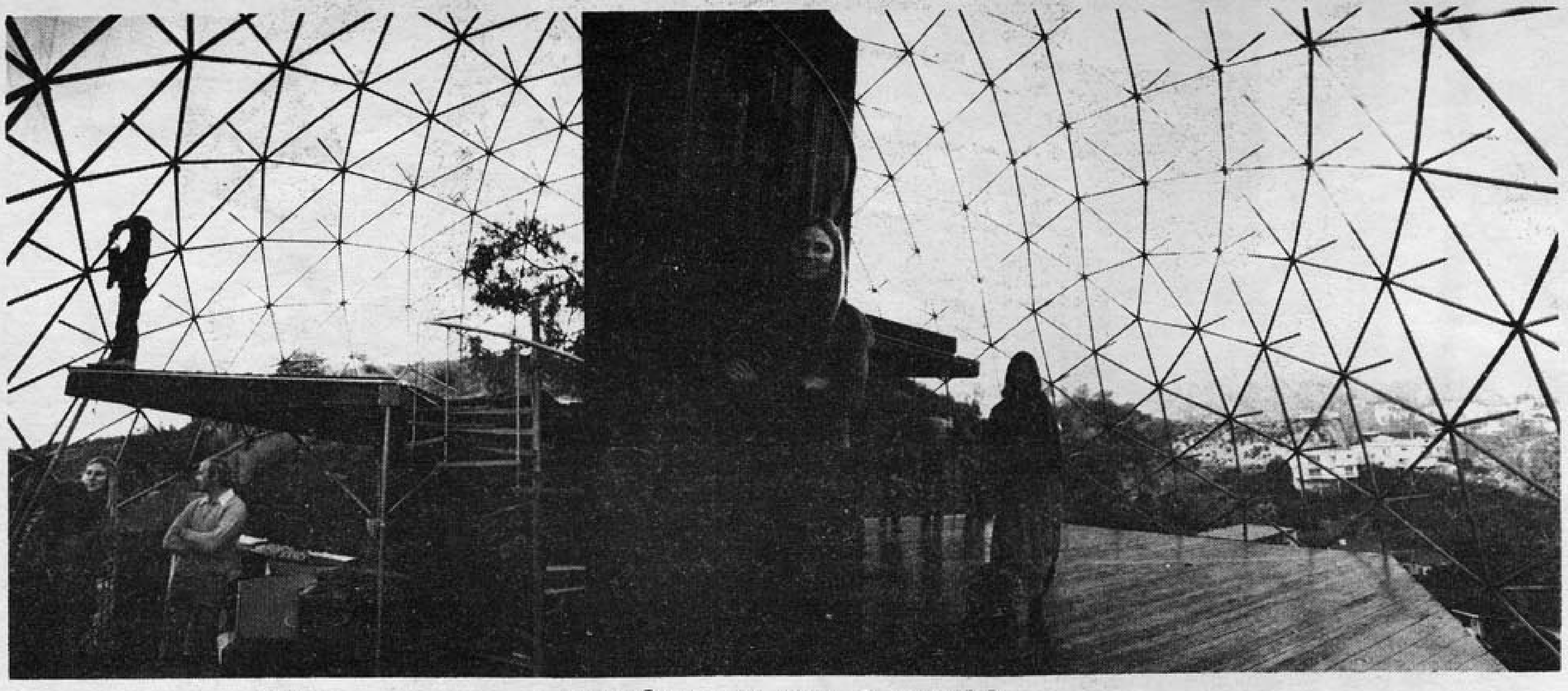




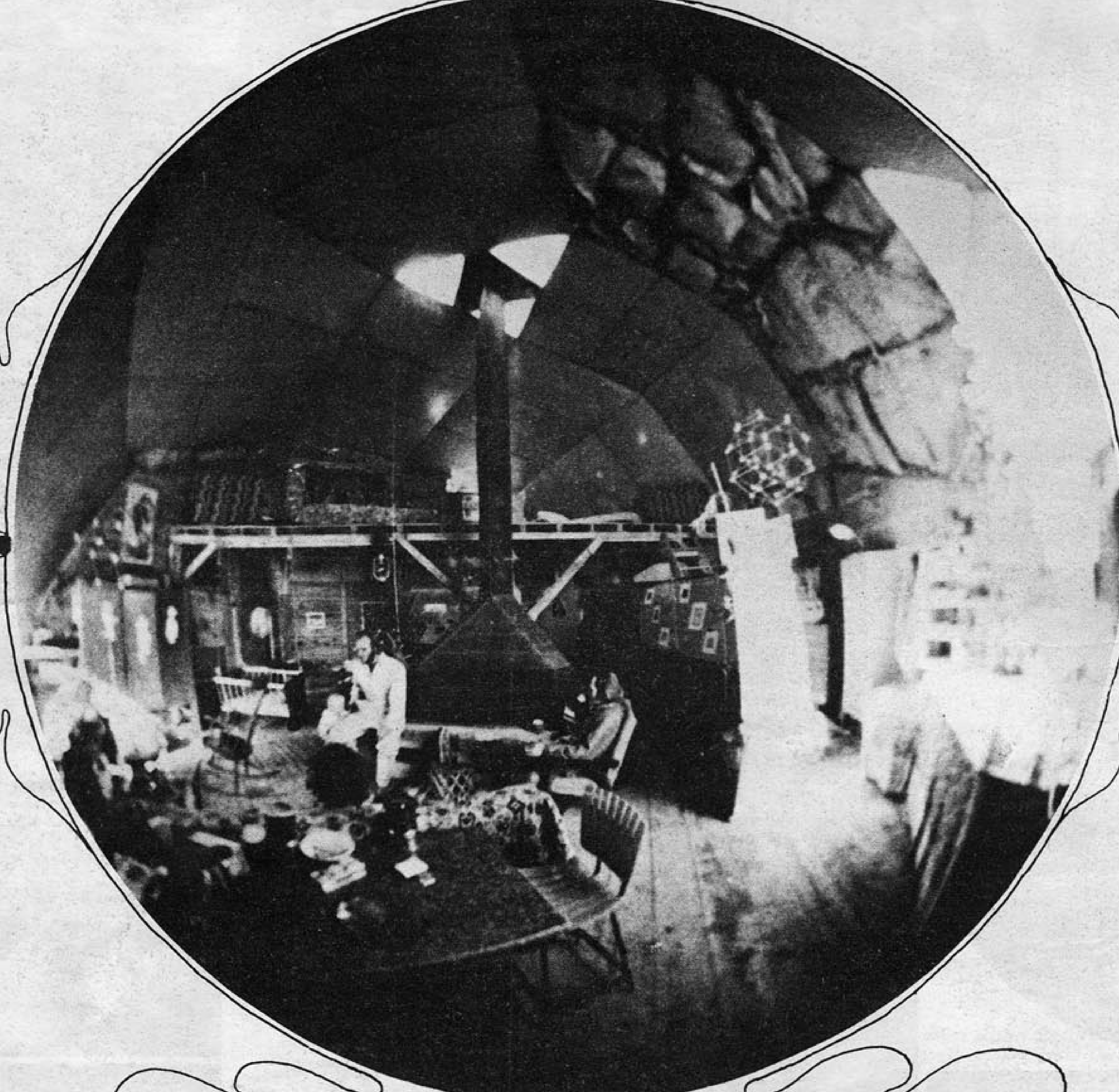


# INSIDE

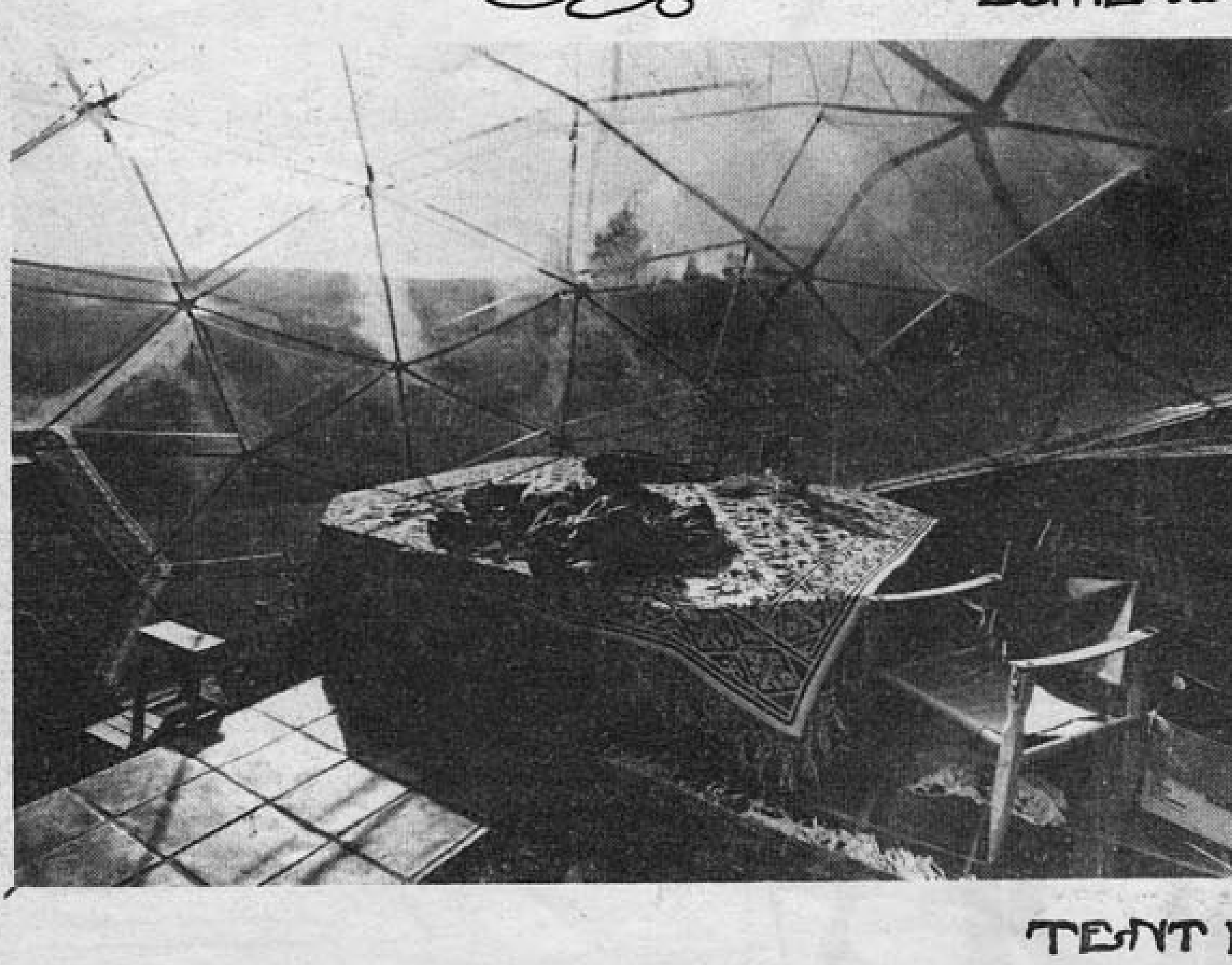
# INSIDE

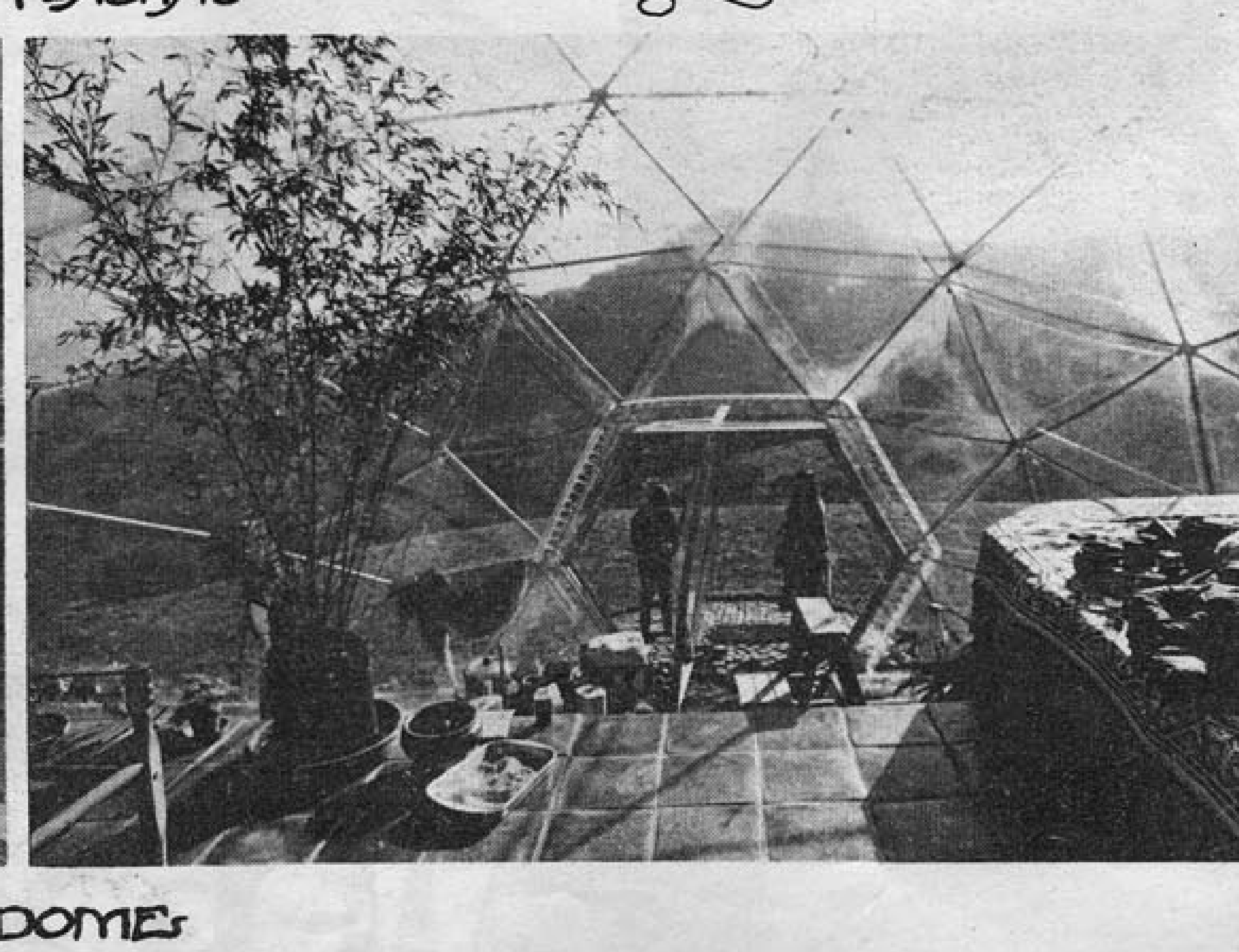


HOLLYWOOD HILLS DOME



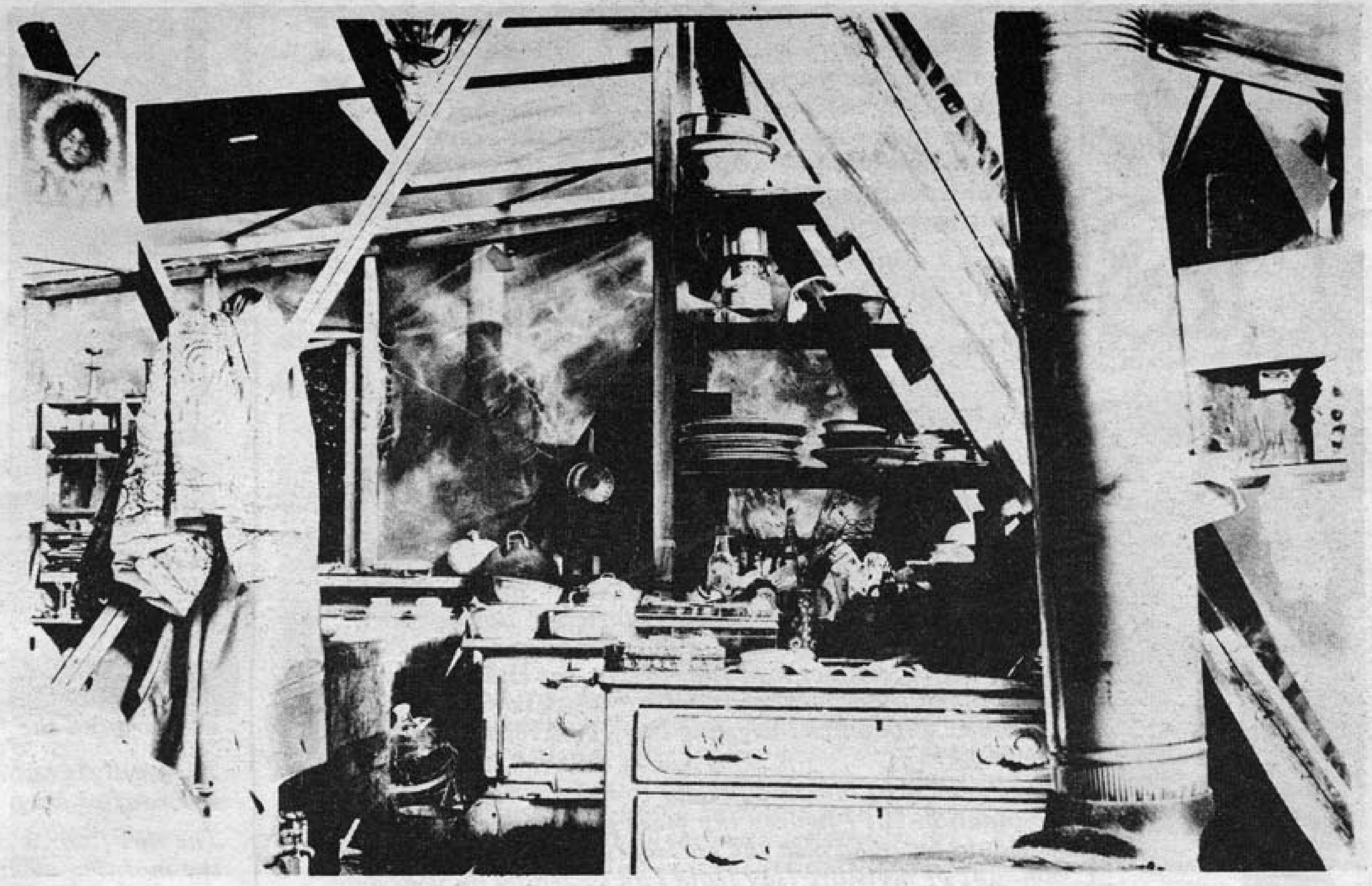
ZOMES at PLACITAS

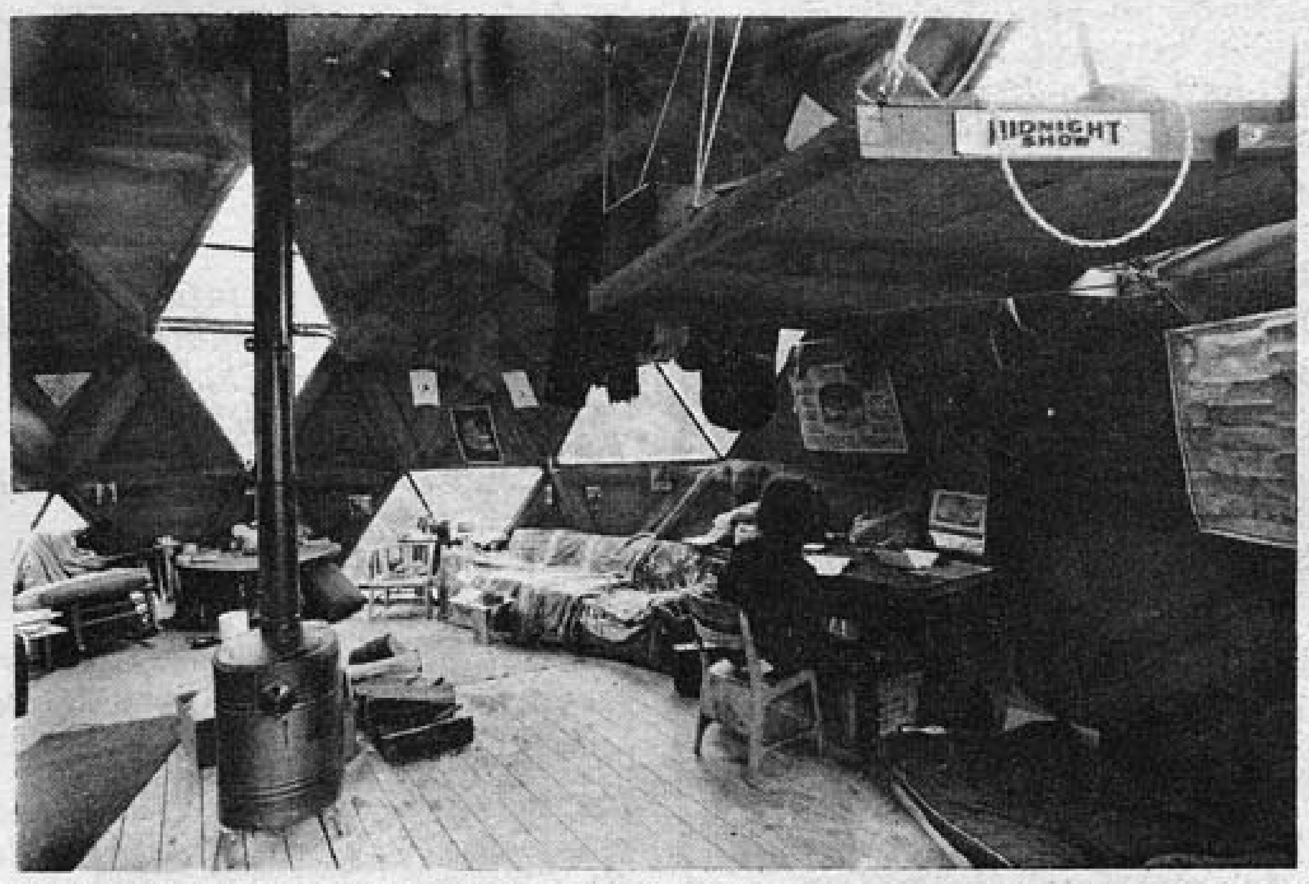


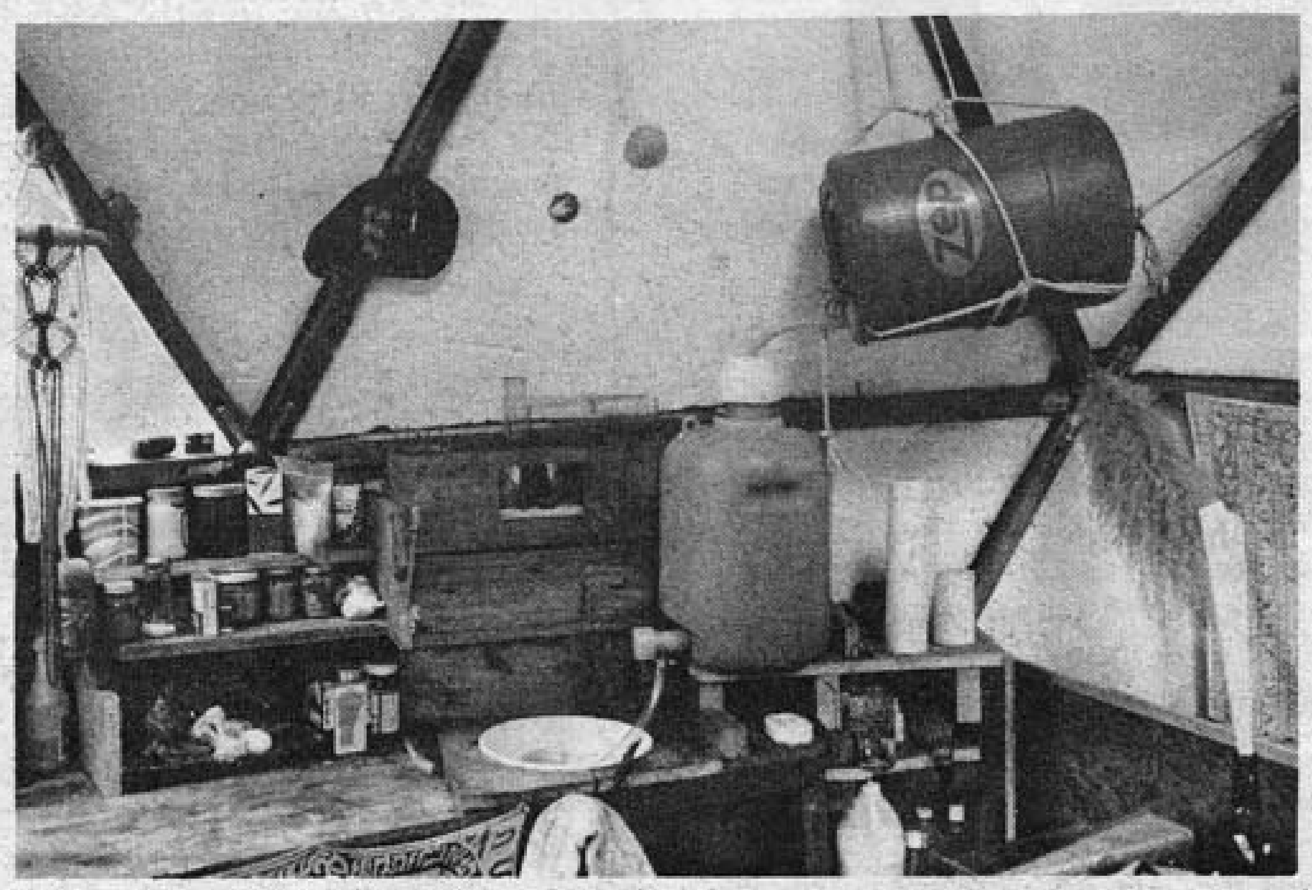


TENT DOMES

# INSIDE

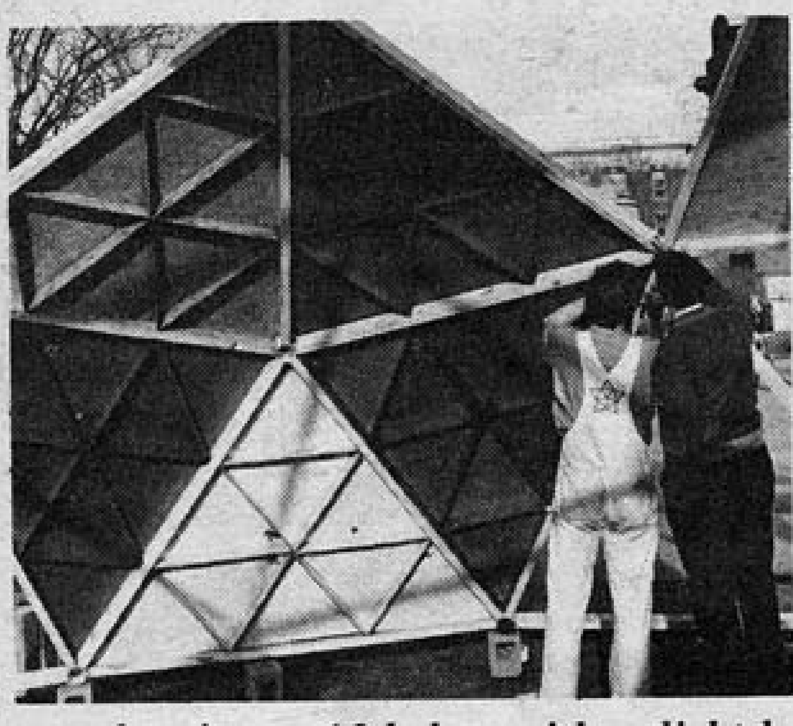






# AT HOME.

# HOT RATS & DIRT FLOORS in MINNESOTA



**JIVIN'**

*Last winter when it was 10 below with a slight breeze blowing, we paced off a circle in the snow and built a 10 meter 3 phase dome frame in the low land. There was a little fire to warm by and we traded off at the ratchet. The members were made of pressure creosoted silo staves which had already been outside for 30 years. And the hubs were the sewer pipe type which are not brittle at 10 below (although at 20° they are about like ice or glass: when struck with a hammer they shatter). When the frame was complete we went back in the house for the rest of the winter and the dome stayed cool at temperatures below −50° (I aint jivin').*

**BIG SHOTS OFF GRAND**

*In Feb. that year we heard there was to be a great environmental teach-in and that the folks at the U of Minn. wanted a little dome to catch everyone's fancy. The next thing we knew we were in conference with the Vice-Pres of the "U", the "U" chief architect and a few other big shots and brothers. They agreed that we would build a 10 m. dome of 2 X 4's and paper mache, cardboard, car-roofs (to demonstrate recycling), etc. and they offered $1000 to go.*

*When we got home we couldn't quite figure out what we had gone and done. We consulted Don Myrhe, a paper mache specialist, and then dropped the idea of paper mache and concentrated our efforts on cardboard and fiberglass.*

**RIBS FROM DUMP**

*After making a few prototype panels (and a fiberglass cello on the side) we scored 100 gals of polyester resin and a big roll of matte. The cardboard came from the Wadina dump. Here's how we worked: you take yer dome panel space and divide it into 9 (or 4) equal triangles. Then we cut box-type cardboard into these small triangles and add 4" flaps. Then we fold the flaps 90° to the face and staple all 9 pieces together with box staples. The flaps become double thick ribs (see photo).*
*The face of the complete panel is fiberglassed, and the back (with the ribs) is resined.*

*When the whole panel is inserted into the 2 X 4 frame the ribs meet the frame and it's strong enough to stand on. We planned on pouring foam insulation into the 4" thick panels prior to installation, but not for this gig. The added strength we were after with the ribs and all was for the snow we figured would build up on the dome should anyone actually use the idea or the dome itself.*

**FUNK WEEKS**

*This kind of panel was only used for about half the panels of the dome. The rest were plywood painted with polyester resin, car roofs, and thin air. The thin air panels gave the dome sort of a pavilion effect—a real funky pavilion effect.*

*The dome was only supposed to be there for 2 weeks so we didn't go too heavy on details.*

*Somehow it lasted until June; but between the rains and the great Student Strike it took it in the ass.*

*The cardboard panels were really far out as far as strength to weight. They also were beautiful to behold. If the foam had been poured into the panels they would have been twice as strong.*

**SUCKS**

*The panels and the whole dome have to be water sealed positively because dry cardboard is like a sponge. It would have to be sealed just as good on the inside as it would on the outside. Of course that could all be done with your chemicals. But in my opinion plastics suck especially when it comes to applying your own. At one climactic point when we were working overtime at night making panels, drinking beer, hearing hot rats at full volume, breathing fumes, stoking the fire....Boom! We were enveloped in flames and we were the hot rats. Everything was on fire from floor to ceiling wall to wall. Only one serious burn resulted and a few lost panels. But right away we all started to think that fiberglass sucks.*

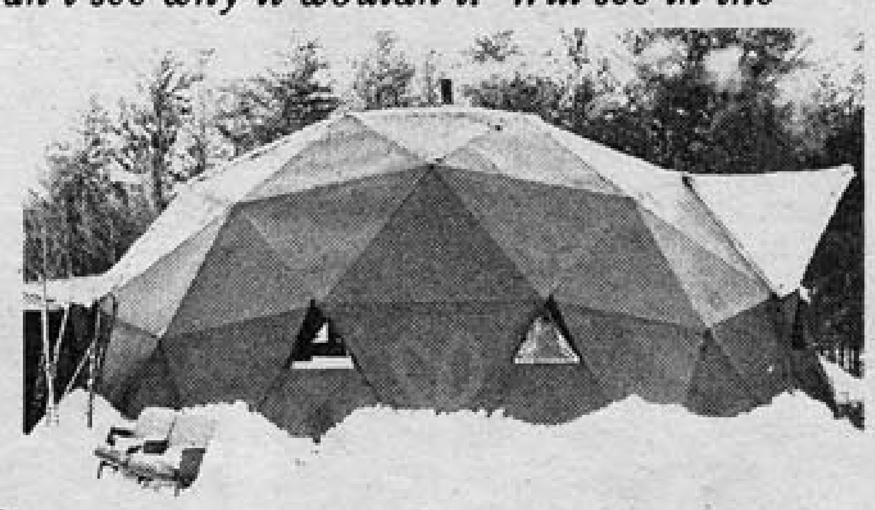
**LITTLE WIGGLES**

*Later this spring we built another dome. This one was up here in the country and it was made of hurry-up plywood. There was some fiberglass left over from Earth Day so we did the seams in fiberglass. So far it seems that the only place on that dome that doesn't leak is the seams (unfortunately, there was a great truck strike and there was no epoxy-paint in Mpls, so exterior latex was applied by the owner—much to his frustration).*

*It wasn't until August that we got going again on the frame we had built the winter before. This dome was to be my house so I took some liberties to do some weird things to it.*

*First of all, it's built on ground which has water standing on in the spring; foundation is only one row of cement blocks dug half way into the ground.*
*(There's one thing I'd like to add here: when the foundation is built after the frame you have to pick the frame up, put it on stands, build the foundation, and put the frame back down on it. The thing is that when you put it back down it doesn't want to sit on all the points it's supposed to, i.e. the weight isn't or might not be distributed evenly on the ground. So what I did was to cut some car innertubes into foot long tubes and pack grease into them; then put one under each hub which touches the ground. With a little wiggling the frame settles right into place.)*
*I had plenty of blocks all ready to build a higher foundation but I figured the more cement blocks the uglier it would be. And also the creosoted frame can stand any amount of moisture (say from rain splashing on it or dew on the grass).*

*But I just used one row of blocks and dug a ditch all around the dome and drained it to lower ground. I don't know if it it will work but can't see why it wouldn't. Will see in the spring.*



**DIRT DOME**

*Also this dome has a dirt floor. Before we moved in I asked all sorts of people about dirt floors, and even the real old guys said I was crazy. With a dirt floor though, there would be no reason at all for a high foundation. I kept thinking of teepees and wigwams. I knew the Chippawa had dirt floors north of here before now. So we went into the winter with a dirt floor.*

*Another thing I did was use ¼" tempered masonite for the skin. The main reason we had put the ribs on the cardboard panels was to hold the weight of the snow we expected to accumulate on the dome. So ¼" masonite spanning 4-5 ft seemed dumb, but this friend of mine, Kelloge said it would be good to have a skinny skin.*

*The skin is tacked on with these little 6¢ nails and then the seams are fiberglassed. I figure the fiberglass is stronger than the nails.*

*The panels that are on the bottom row overlap the foundation and come within an inch or 2 of the ground.*

*Tempered masonite is supposedly real resistant to water. The scrap pieces that I stacked under the eves of our garage got dripped on all day every day for the whole month of October and part of November with no bad effects whatever.*

**HAWK OUT, HEAVY CHANGES**

*However, now in January, there is no snow accumulation on the dome to speak of, but the masonite sags under its own weight. We've had a couple of feet of snow so far and there's only an inch or so on a few spots; the rest of the dome is bare. All the snow simply slides off the smooth laquered finish and banks up around the bottom which is really good for keeping the Hawk out from under your house.*

*The sagging is a little distressing, but I'm not too sorried because the way the styrofoam sheets are put up inside will hold the skin up for a long time.*

*As for leaking rain, the only problem we had in the fall rain was a few flaws in the fiberglassing which I will repair in the spring. I think fiberglass seams are really good.*

*The main water problem is condensation on the inside. The skin is so tight that it rains every morning about 10:00 especially if the sun is out. The moisture freezes at night and melts in the morning. I plan to vent each panel in the spring.*

*The skin of this dome, fiberglass laquer, masonite and all go through some heavy changes during the day. I've taped a thermometer to the outside during a sunny day and registered 90°F. That night the reading was −36°F. That is 126° variation in less than 24 hours.*

**JAM IN**

*The insulation is done with 2 X 8 sheets of 1" thick white foam. I used 2 layers of it. The first layer is cut to size and jammed into place between the members. It holds itself in. No glue no nothing—just jam it!*

*The second layer is nailed over the members with lathe strips (it turned out that on a 10 meter dome the parallel great circles were exactly 6 ft apart, so 3 rows of 2 X 8 fits perfectly all around). The 1" thick foam bends a lot more than the 2" stuff. 2" of foam is plenty for sub zero weather even with a ¼" thick skin.*

**NO DUSTY JIG**

*Another problem which I handled lightly was what they call "storm windows". My dad recommended 3 layers of glass to ward off the north wind. For a while I planned on at least the traditional 2 layers. But I soon found out that one layer of 4 mil vinyl was just the ticket. There are 15 triangular portholes at eye level and one full-panel skylight. All but 2 of the portholes are sealed for the winter. One on the south and one on the west open. That's more than enough ventilation with the super floor vent around the full circumference.*

*The skylight has a 3 dimensional storm window which acts as a roof to keep snow off it.*

*The dirt floor is one of the warmest floors ever devised. In the morning when the wood fire is low and it's 30° outside we hop out of bed in bare feet without doing a jig. The only problem with a dirt floor is that it's hard to keep clean. We have rugs on the floor to facilitate cleaning but they don't really work too good. A clay floor would probably be better.*

**SPACED**

*Most houses you go into around here in the winter (which is longer than the summer) are hot and stuffy. If everyone is sitting around a table smoking and blowing a lot of hot air it's worse. But in this dome the climate is a gas. There is a 1' hole in the top with a flat piece of plexiglas over it.*

*This small hole seems to be enough (with the draft created by all the cold air outside) to suck out all the dog breath.*

*The double barrel wood heater is real good and I wouldn't recommend any other kind. Unless maybe a single barrel which is pretty good.*

*I run a kitchen hood exhaust thing using a "T" off the stove pipe. It's a good deal for doing stinky work like fiberglassing or cooking cabbage under. There is no loft in this dome which gives me a spaced out feeling.*

**THE ORGANIC DOME**

*I plan on building a few more domes in the spring and next summer. My big dream idea is still to use paper mache. Paper mache houses have been built in the Orient for thousands of years using wheat paste and persimmon juice for waterproofing.*

*Laminated newspaper soaked with wallpaper paste is plenty strong enough if it can be waterproofed.*

*Another way to do it would be (and this is the way I will try in the spring) to make a mixer like a cement mixer for paper mache. The newspaper would be shredded and mixed with a waterproof glue then poured into panel forms along with willow branches or cattail reeds from the swamps and then pressed with heavy weights into a light, strong, porous panel of paper mache. Then to cinch it and seal it, a laminated paper mache face would be applied to front and backside of the panel. This would also add a great deal of strength.*

*The paper mache panel would hopefully bring the price of a dome down into a reasonable range. There aren't too many people that I know who can come up with the $Grande it takes to build these domes in the ways they've been built so far, flaunting industrial gimmicks on $200 whims.*

*Another system would be simply boards and stucco. Tear down an old building get all the 2 X 4's and wallboards and floorboards. Build a dome, cover it with boards then stucco it or put mud on it or shit on it. That would probably cost $100. for a 10 meter dome. There would be a little extra work involved, but what are we living for. What a gas!*

*I can't say enough about what I call "organic" houses. That is houses made of material that doesn't come through the system, or material which the system has discarded.*

**BIG FINISH**

*Book One was filled with plastic gimmicks—toy houses. Plastic is fun to work with and it offers big deals in the "future" but in the present or now right now (!) the world is being gunged out, snowed under, whitewashed, polluted by the white man's white collar and fat purse.*

*Plastic is simply not practical. This is not the future. People need houses now. People want freedom now. Freedom from plasticity.*

*Store-bought materials are not as easily obtainable as they seem. The unaccounted costs are monstrous! Why waste time and life and money and water and air fooling around with systematic construction? We should try to keep the shit level at a minimum. Use as little "money" as possible. Recycle waste as much as possible. Manufacture our own parts as much as possible.*

*Keep it clean as much as possible.*

*Think before you strike. Love,*

*John*
*Verndale, Minnesota*

# Red Rockers

The Red Rockers built a 60' dome because: we like living together "in a heap" with one kitchen and lots of shared space; we dig science and futuristic stuff; we wanted our home to have a structural bias against individualism and for communism; we like doing big things together.

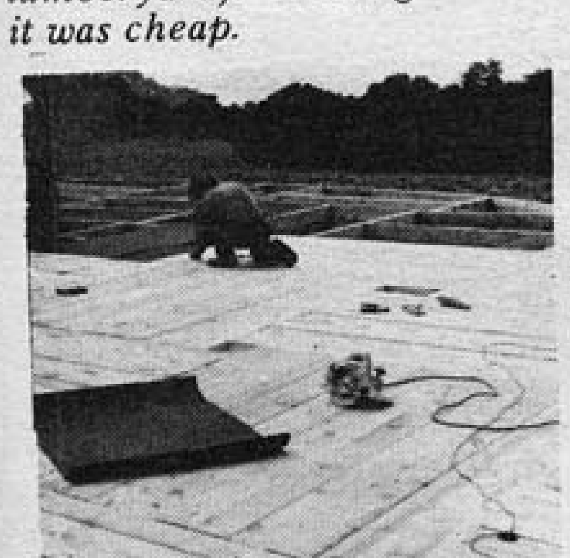
There are 12 to 20 Red Rocker women, children and men. Our name refers to our culture, our politics and our geography. We live in a high mountain canyon with no electricity and a road nothing bigger than a pickup can travel. We borrowed a 2500 watt generator and kept our two pickups busy hauling wood and supplies. Other tools included: a 17 inch Sears chainsaw; a 2 hp Rockwell Delta table saw; a 2 hp Sears circular saw; a couple of light power drills; a strapper(more about this later); the usual hammers, levels, chalklines etc. We borrowed an oxyacetylene torch for cutting hubs.

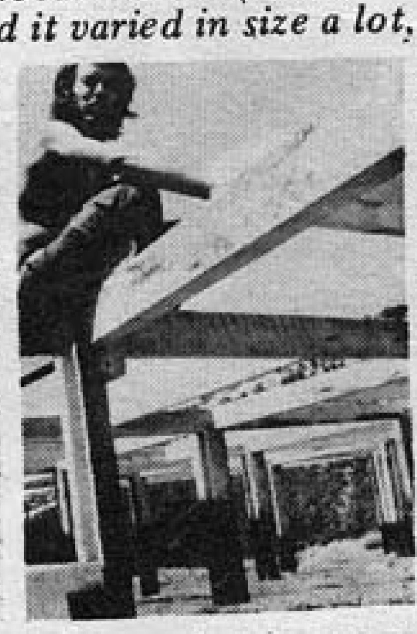
The site we picked drops about 6 ft across our diameter. We laid out a 70 ft floor(dome plus porch) with stakes and string and marked spots for pilings a maximum of 7 ft apart. 102 holes were blasted, then dug.

Dynamite is cheap and easy to use(read the Blaster's Handbook published by DuPont) but not very precise. The distances between our pilings varied a lot, and we had to cut each joist to size. It would have been cheaper, for a structure this size, to have hired a tractor with a posthole digger and set the pilings in an exact grid.

We used 8 X 10" railroad tie ends and seconds for pilings. They were painted with tar and set in with rocks and dirt, then levelled with a chainsaw. Some of the pilings had to be split, as we divided our floor into three levels: a large kitchen area raised 12" above the main floor; and a fireplace "pit" area dropped 30".

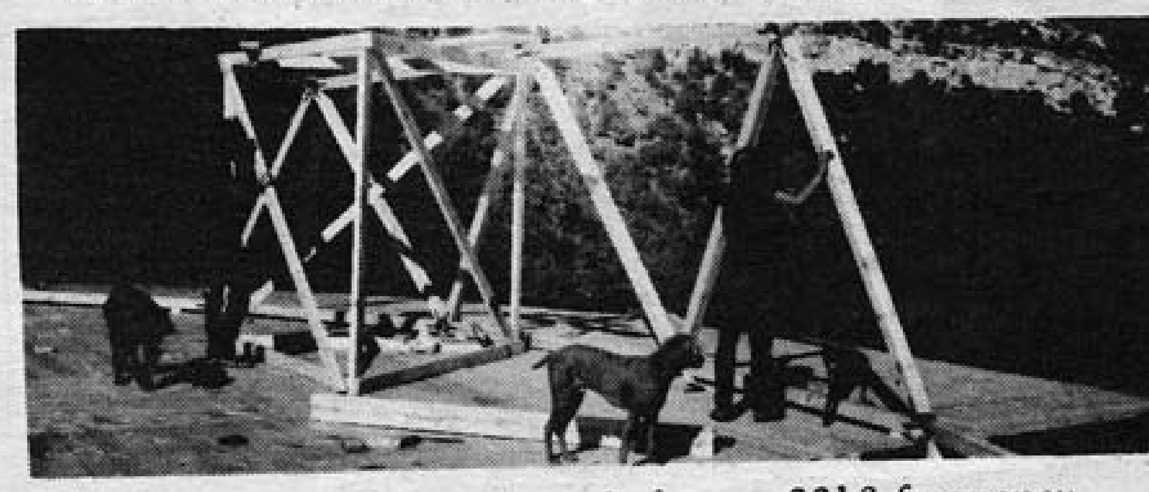
3 X 6"s were used for joists and "fat" 2 X 6"s for stringers. We got all our lumber from a local sawmill(not a lumberyard). It was green and it varied in size a lot, but it was cheap.





We stapled tarpaper over the joists and stringers and then laid 2 X 6" floorboards, alternating the direction of each 7 to 8 ft section so that the floor looks like a checkerboard. The tarpaper is to prevent drafts. Unfortunately, water collected between it and the boards while the floor was uncovered. It's probably still there.

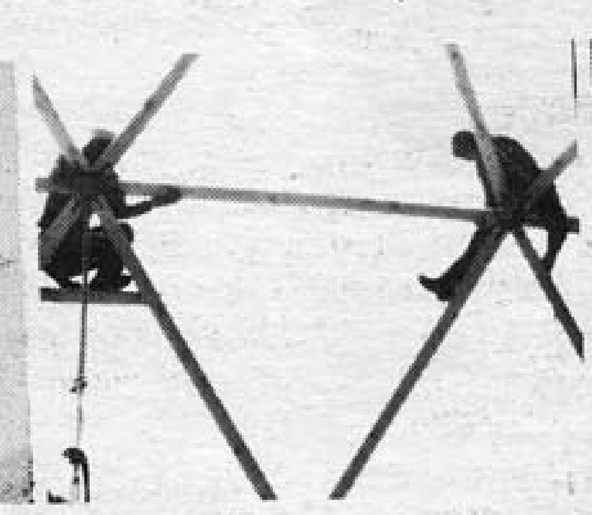
It took us almost two months to build the floor. The dome structure started going up in September 1970.

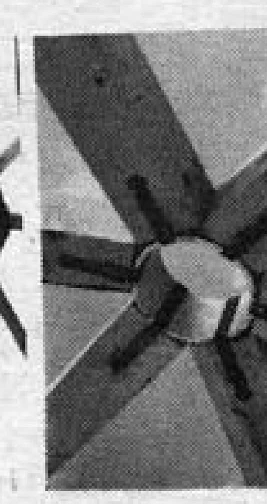


We had only built one dome before—a 22' 3-frequency Celotex covered structure which served as our kitchen while we were living in shacks and tipis—and we didn't feel ready to handle a high frequency dome. A 4-frequency hemisphere seemed to offer the best combination of simplicity and strength. Steve Baer told us it would probably work. Calculating the strut lengths from Domebook One, we built a model. We decided to use steel strap to put the dome together, and to use 4 X 4" struts and 7" diameter steel pipe hubs.

The 270 struts were cut with a radial arm saw loaned by a neighboring commune. They varied in length from about 7 ft to about 9 ft. 1" holes were drilled 3" from the ends of the struts to accomodate the strap. We also cut 4" sections of 1" half-round dowel to put in the holes so the strap would be pulling across a flat surface.

We put the dome together with a strapper($60) and ¾"/ .027" steel strap. This was the heaviest strap our tool would take. We should have used a larger strapper and heavier strap, as we had to double strap in lots of places and had a few broken straps; but our unit worked pretty good.





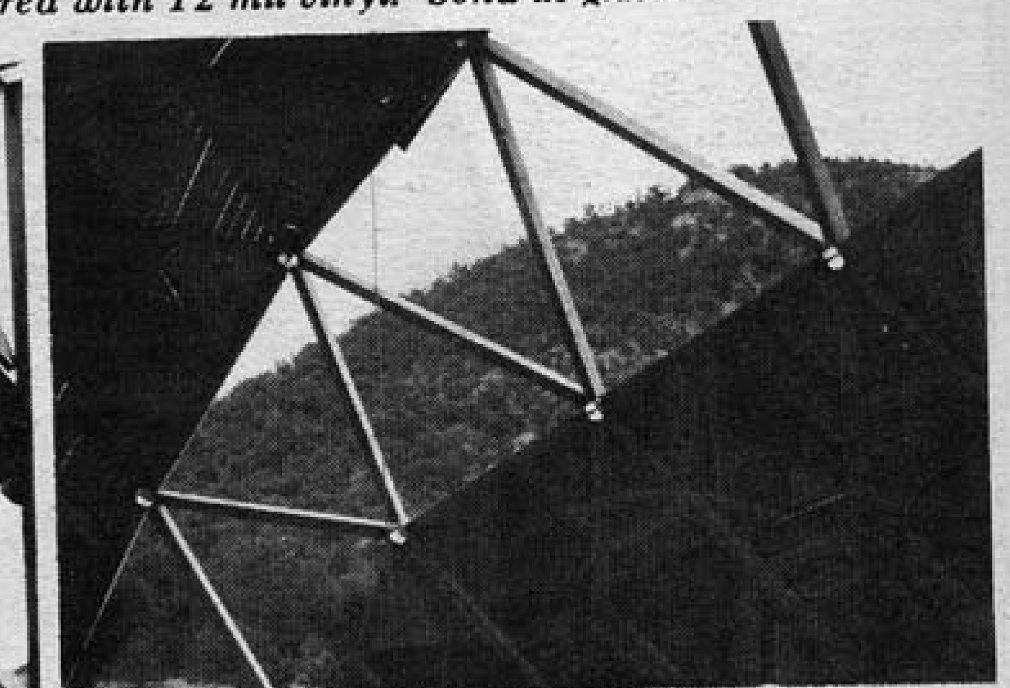
One of the advantages of a hemisphere with an even number of frequencies is that the bottom row of hubs sits flat on the floor. We strapped them to the floorboards and started going up. As we got higher we were happy to find out that the strap held all the struts in place and we never had to use support poles. We double strapped in many places just to be sure.

We built the scaffold out of 8' 2 X 4"s put together in triangular modules. It had to be strong enough to support 2 or 3 people plus a 30-40 lb strut, yet light enough to move around. Toward the end, when it was over 20 ft tall, it had to be stabilized with ropes, and even then it was pretty scary.

The struts went up in a week, with no real problems. Then there was a big party.

Once all the struts were in place, some of the straps were loose, and we replaced them. None were broken. Most of the "horizontal" struts would move when we climbed on them, but we got used to that.

We decided on a long arc of window area to follow the sun, 2 doors(full triangles) and full triangle windows at the bottoms of 3 of the pentagons. Right now the windows are covered with 12 mil vinyl. Send us glass!



Skinning the dome was a special problem, since the triangles were all too large to cover with single sheets of plywood. We used small ¾" and 5/8" CD plywood triangles inverted inside each triangle of struts, and then filled in the 3 corner triangles that this created with 1 X 4"s. The 1 X 4"s were cut on jigs and hauled up in numbered sets to be nailed in place.

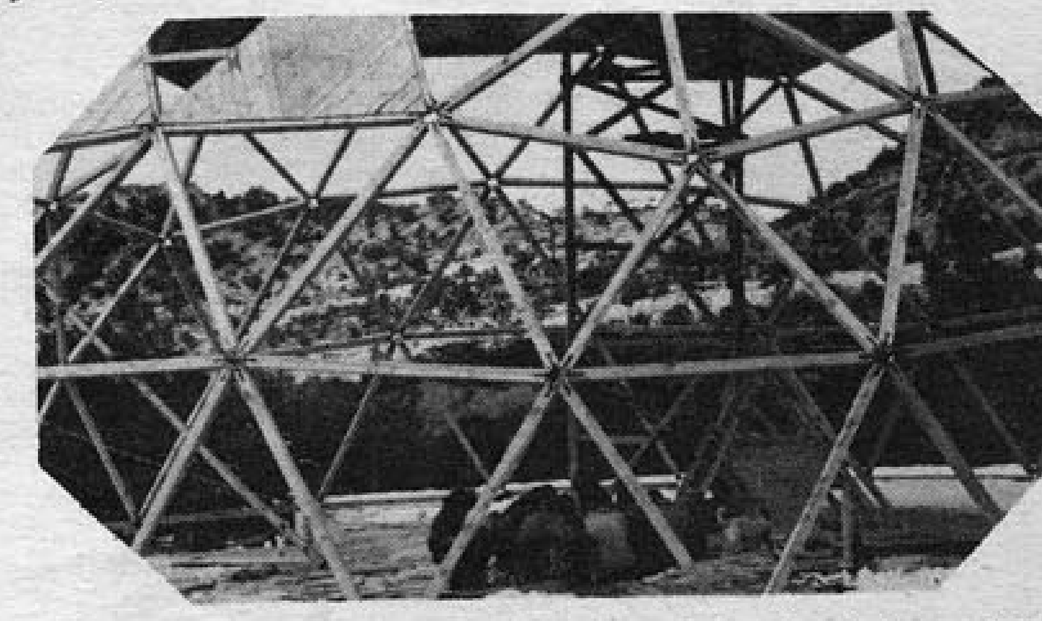
We started covering the dome from the top down. When it was about ¼ skinned a heavy snow fell. The snow load caused the dome to bulge around the perimeter near the base: 3 straps broke and the hubs popped out about a foot. The top of the dome must have dropped but we never measured how far. We were too busy double strapping the hubs that hadn't come loose and trying to get 2 feet of snow off the top of the dome. We finally got the dome back into shape with a come-along and the strapper(which is really a winch) and started skinning from the bottom up. If the dome had been put together with anything but strap, it would have been almost impossible to fix.

Cover your big dome from the bottom up.

We covered the skin with tarpaper as we went along, to protect the cheap plywood. Then we hauled 6 tons of T-lock shingles up the road. Then we hauled them back down when somebody pointed out that they would form a giant tube but never a dome. We covered the dome with 3 tab strip shingles. It doesn't leak.

Probably our biggest single mistake was not putting a piling under each of the bottom hubs. The joists are not strong enough to support over 20 tons of dome, and many of them are breaking. We'll have to jack them up and put uprights under the hubs. We also notched our joists, which weakened them.

The most important thing we learned building this dome is that women baking bread while "dudes" build domes is sexist bullshit. We tried very hard to keep an oppresive division of labor from developing and we did pretty well: all the Red Rockers are domebuilders, not just the men. Brothers and sisters, get high together, trust in the Lord, make domes and Revolution together. There's no point in building revolutionary structures to shelter reactionary life-styles.



We've been living in the dome since Thanksgiving, when we finished skinning it. It's heated with two Ashley woodstoves with 20' stovepipes inside. Doors are no problem on a dome this size since they can be fit into single triangles. We haven't started on the sleeping platform yet, but eventually we'll have this 30 ft high space divided into 2 or even 3 levels. Right now we're insulating with 12 ft styrofoam 1 X 4"s—industrial waste donated by a groovy businessman. We're gluing these strips together and cutting them with a hot wire into triangular units to be painted and put up. We plan to leave the struts exposed.

The Red Rockers

# Writers

Mario, having cigarette after
putting up the first row

### Erika & Mario

*Hi*

*This letter will sound maybe a bit funny to you, but i actually beg for a domebook, not for myself but for my man who is in a penetentery for 9 month on a hashbust. He got busted allmost 3 years ago in Toronto, he is french canadian, i am german, since then we own 340 acres of land with 6 other people. We are a comunety and startet to build geodesic domes last summer, 2 last summer and one this summer. Mario build the first one. He used PVC pipe that is extendet outward 5 inches so one can climb on it and we have colored plastic in the hubs inside and outside which is simply ½" of PVC pipe one size bigger to which the plastic is glued and we can just slip it over. So the sun raises that come in are green, orange, red, blue, etc.*

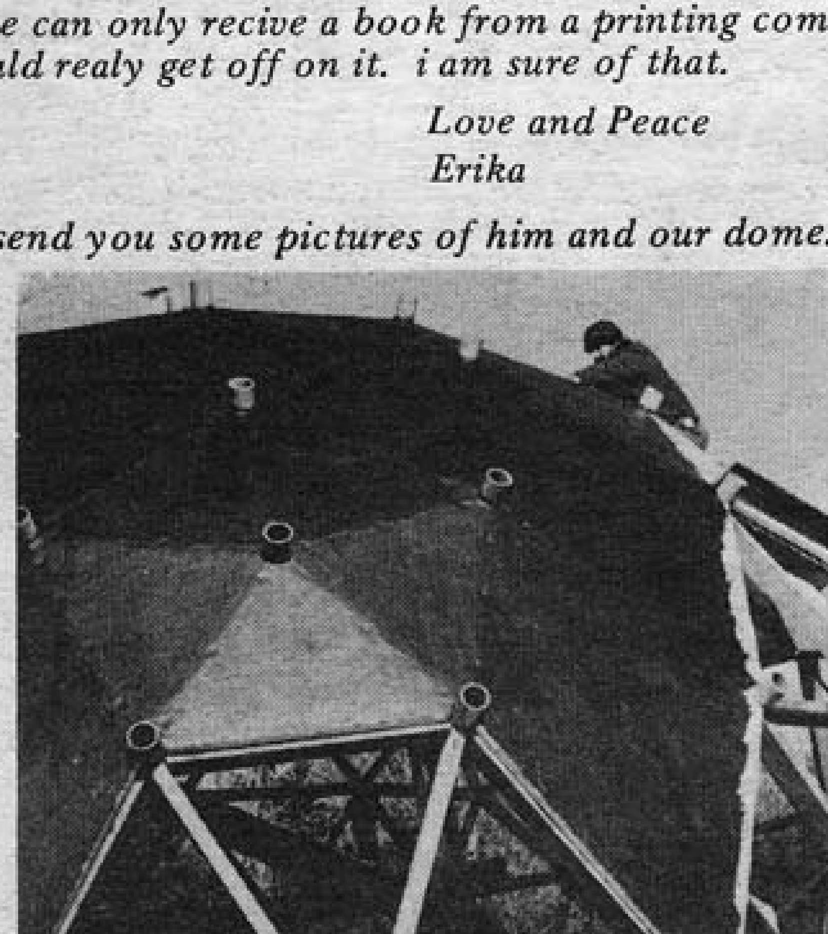
*We lived in our dome allreddy last winter, this will be my second one and it gets down to 40° below zerro here. The styrofoam is 3" thick and keeps the heat in realy good. Last year we had a cookstove and a boxstove (wood) this year i have an oilstove and a boxstove.*

*We make handicrafts to stay alive but money is allways sparce.*

*So i beg you to send one of your books to*
*Mario*
*Box 300*
*Millbrook, Ont.,*
*Canada*
*Since he can only recive a book from a printing company. He would realy get off on it. i am sure of that.*

*Love and Peace*
*Erika*

*P.S. I send you some pictures of him and our dome.*



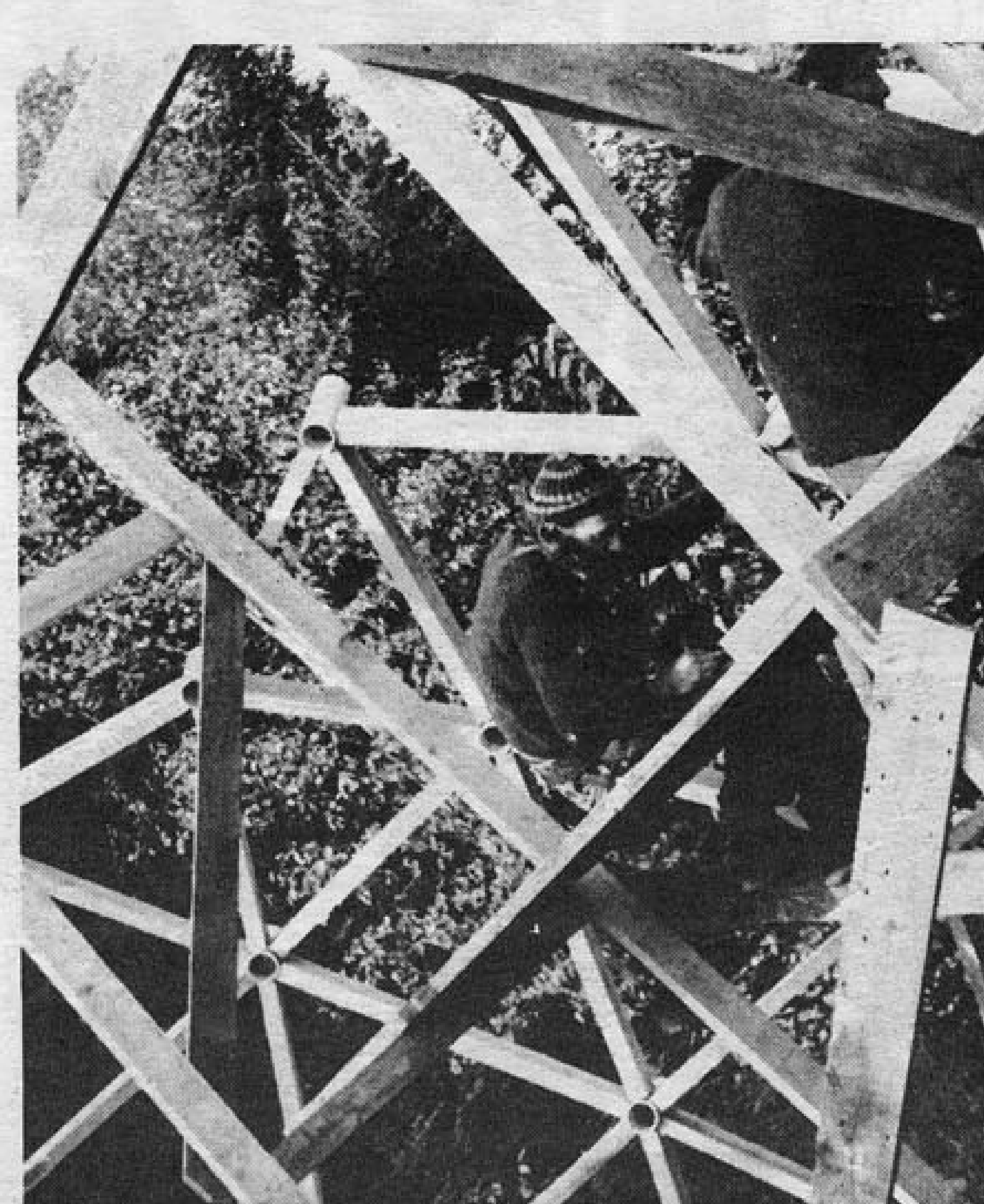
Mario, covering the dome

*Hallo Dome people*

*i love you for sending your Domebook No. 1 to Mario, he was very happy and exited about it, now he can trip out on it.....*
*Our domes are covert with styrofoam and a waterrepellend emolsion (Bulldog gripp) they are very cheap domes, cost only 500 dollars, but we would like to build a big one, a workshop soon.*

*The styrofoam is a very good insulater, since it goes down to 45 below zero in this country, right now thats what it is outside...*

*By for now*
*go lightly*
*love and peace,*
*Erika and Mario*



Kenny, Mario and Jock

*There is definitely a noise problem in an unpartitioned dome. You'll need partitions if more than one activity at a time will be going on. Sound permeates the space as efficiently as heat. Look through the book for various ideas on dividing space. An important thing to me, in considering dividing up a dome, is to leave the top space open, to avoid partitions that go all the way up. This way your eye will be able to roam over the shell.*

### Cardboard

*In the Sept. 70 Whole Earth Catalog (p. 14) somebody suggests these special cardboard panels. I tried some. They are very strong, good insulators, and can be waterproofed. I am insulating a garage with them.*

*They use cardboard boxes that appliance stores throw away like mad. They could be used as dome panels (covered w/a parachute for color?) or as pop-in insulators. You'll have to get a copy, I just can't explain them, and the guy writes a nice letter (he's in prison).*

*Mike Branhut*
*Philadelphia, Pennsylvania*

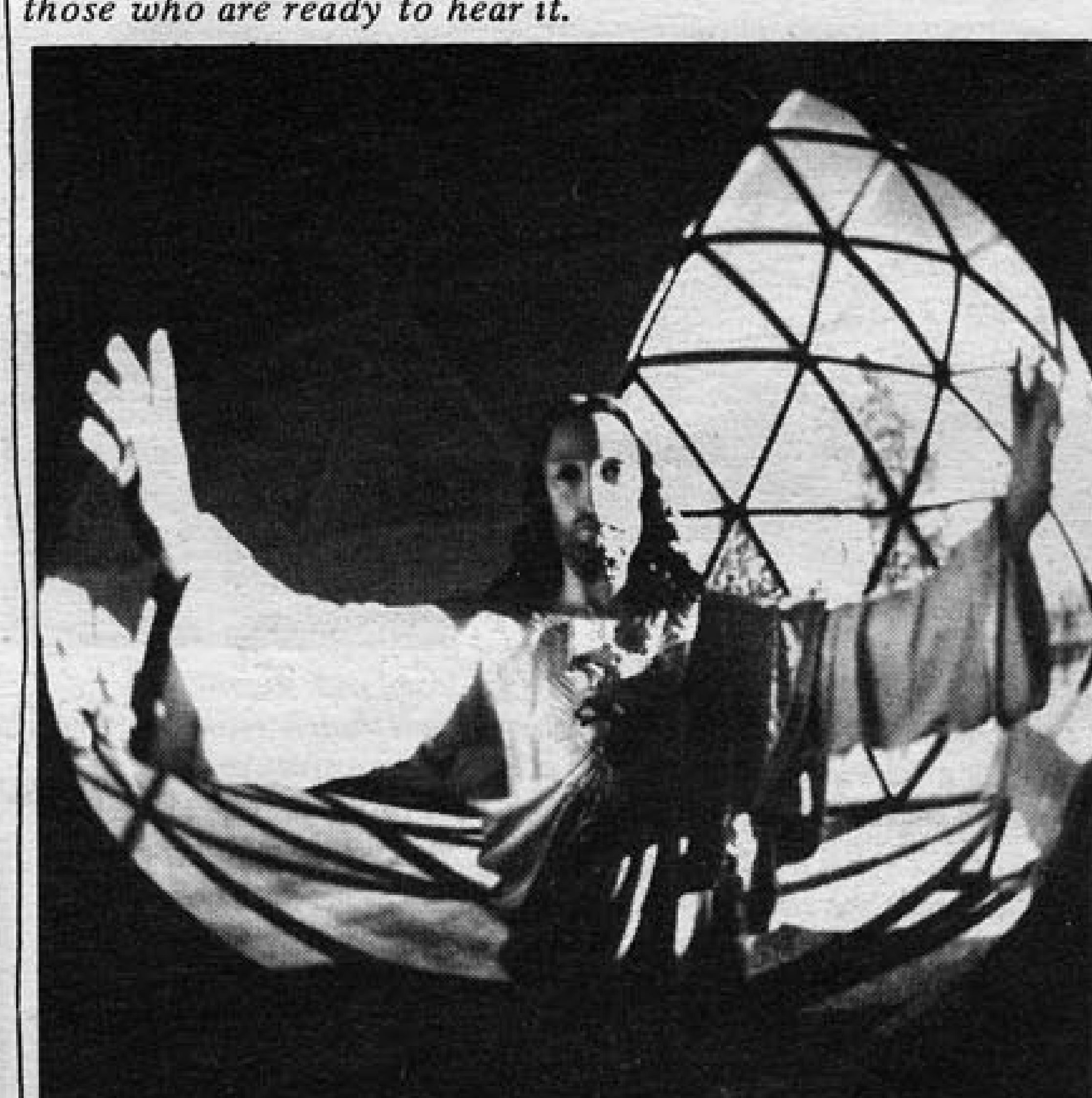
*when you watch sun come over a mountain in the early mornin you're spinning forwards*

*There are 67,000 nails in the average house.*

### Fable

*hidden secrets of the cubo octahedron.*

*when 12 spheres are packed around a central sphere, it results in the cubo octahedron, what Fuller calls the vector equilibrium. This is the first solid the most simple structure that has a nucleus. The tetrahedron, octahedron, hexahedron, dodecahedron, and icosahedron do not have a nucleus. But the cubo oct does. It is the basic building block of the universe. To convey this knowledge, the ancients, in their infinite wisdom deemed that simple folk would not comprehend, and made up the story of Jesus and his twelve disciples. Jesus the nucleus, the disciples in orbit about him. When Jesus was crucified the 12 spheres collapsed into an icosahedron, which is the largest number of close packed spheres without a nucleus. It you look at dowel models of these solids, the cubo octahedron is unstable, the icosa is stable as it's omni-triangulated. The fable of Jesus indicates to he who is attentive that there should be no leaders, as all leaders are insane. The fable also indicates what the ancients deemed man at that time unable to comprehend: that the icosahedron is the foundation of worship. Men mistakenly based their religion and churches on the cube (hexahedron), and to this day the religion is based on the rectilinear grid of the city, the rectangular shape of Bank of America skyscrapers and dollar bills. Now that we are entering into a new age, as hinted at over recent years, a new religion is about to emerge, its symbol the icosahedron, and the structure of the finite universe is about to be unveiled to those who are ready to hear it.*



*Man is about to enter into the next phase of evolution, wherein artificial organs will begin replacing failing ones, computers are being microminiaturized and will soon fit inside the human skull, we are now getting accustomed to a new shape, that of the triacon dome for example—shiny aluminum, low disk, or the zafu dome—the proper shape for hyper-space jumps. When the next phase is completed, select worshipers of the proper symbology will be selected for total conversion and will assume the shape of flying saucers. The ancients have, since Atlantis had ready the ruby maser star power source, which is stored deep within Mt. Tamalpais, Mill Valley, Calif. When the mountain parts to release the ruby machine, there will be the world's largest rock festival, with everyone on earth attending and filling California from Daly City to Petaluma. The Beatles will appear together once again to demonstrate that they are agents of the ancients. The saucer angels will connect with the power source and leap through Dymaxion space time/warp. Man will be on his way to fulfilling his destiny in Universe and there will soon be McDonald hamburgers available throughout space.*

*Anthony Arrakis*

# ISLA VISTA DOME

*Isla Vista is a practically all young hip community right next to the University of California near Santa Barbara. Back in Spring 1970, after the Cambodia Invasion, students were shot at Kent State, the Bank of America was bombed and and burned in I. V. Battles raged for weeks on the streets, cops imported from L.A. roamed the town, harrasing many non-participants. The people of I. V. expressed during these weeks the way they had been exploited-- high rents and non-breakable leases, high prices, and general rip off by outside operators, besides their opposition to the war.*

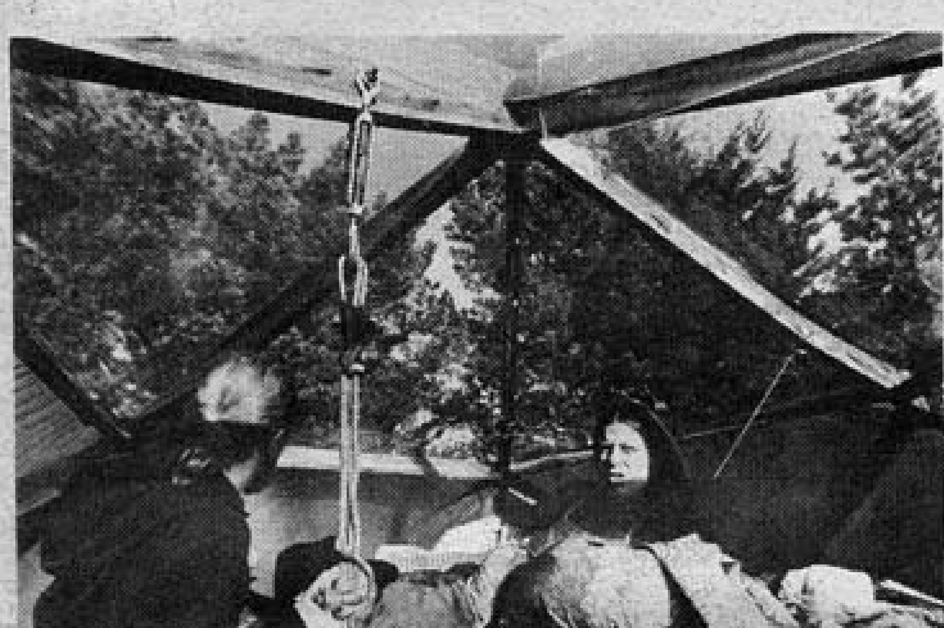
*Out of all this came a sense of community in I. V. and some money and effort by the university to take some responsibility for the place where most all of its students live. Institutions sleepwalk, don't usually wake up until they're jabbed The battles in I. V. were brutal, many people not involved were hurt, one was killed.*

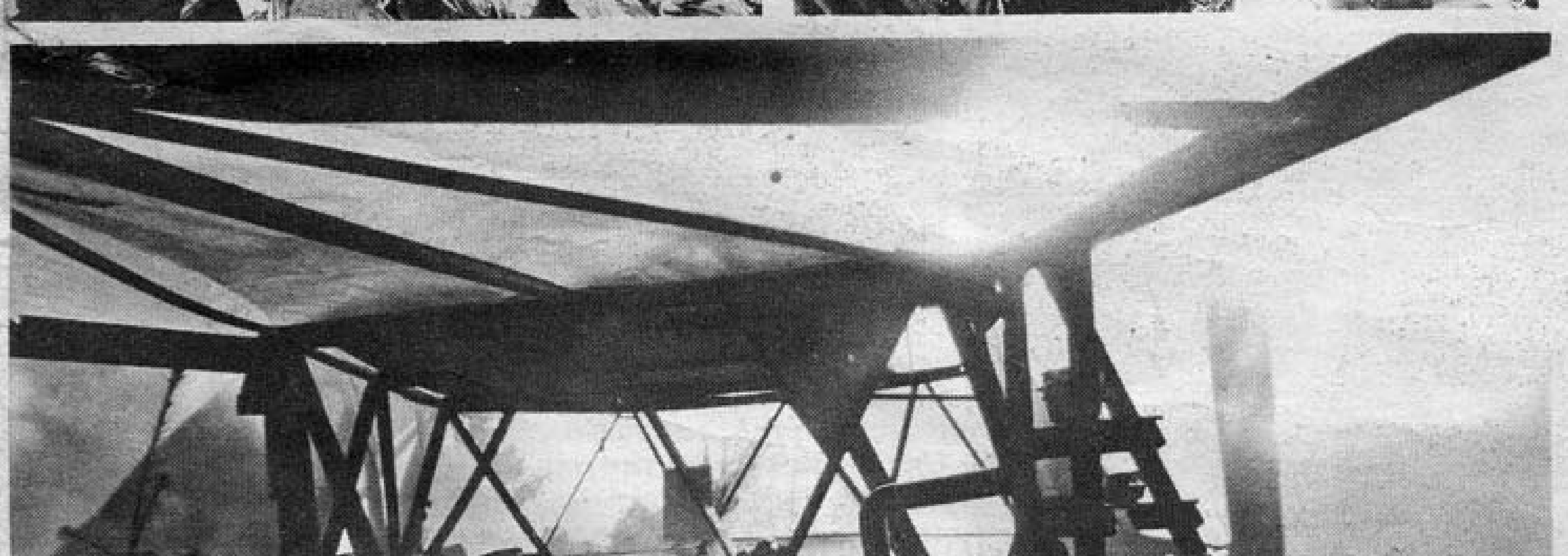
*Through the I. V. Community Council requests for the money ($600,000) started coming in. Money has already gone for a methadone program, a street theatre group, a community printing shop, etc. The largest request was for a Community Center, a building or buildings for music, meetings, information exchange, workshops, but most important, a place to learn what the school wasn't teaching-- organic gardening, building, how to leave the city and survive.*

*Dave Reisman and some of the other students on the council got into domes, and wanted to learn how to build them so they could build the center themselves. They put up a dome in Perfect Park in I. V. during a market day, and the community responded, it was an amazing day. They used washer hubs and old 2 x 4's for struts, and the dome went up in about three hours.*

*Recently heard that the Community voted to build the Center, and that the University has given some land for the project right on what is the property line between the campus an I. V. The hope is that the student built center in that location will start bringing things together.*

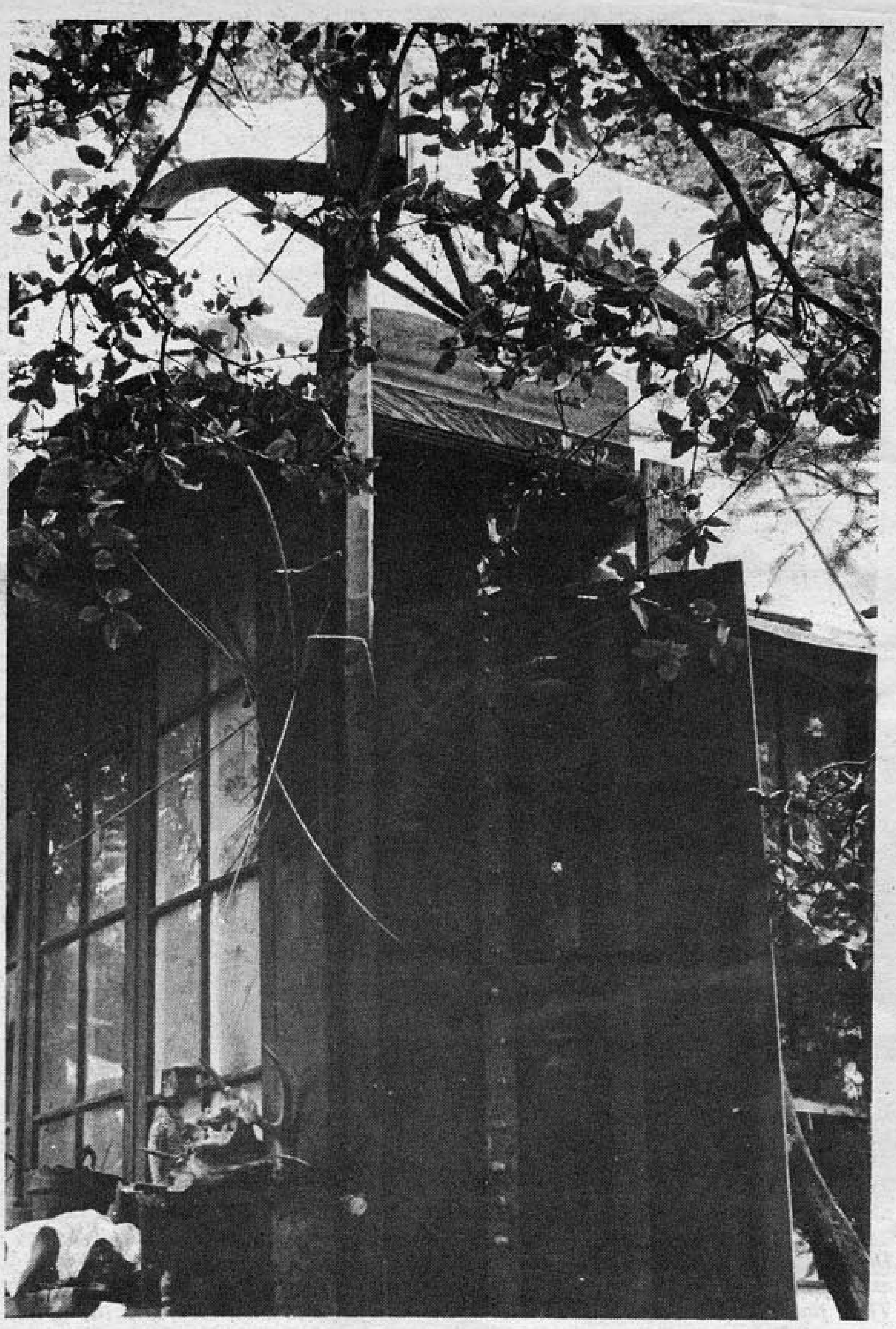
*Bob Easton*
*Santa Barbara*





# SCROUNGED ICOSA

**Troll and Marylyn's icosahedron was originally built for $35. Just about everything in it is scrounged. An Ashley top fitted onto the body of a different wood stove, the only posts in the home are tree branches...Loft hangs from the center, clear plastic so they can watch stars at night, Troll tells how once in a windy storm, the plastic blew off, and suddenly they were in bed outside.**



### ...A PERCEPTIVE SCAVENGER

*...A perceptive scavenger is able to envision the use of some unusual material in his prospective dwelling merely because his vision of the structure is both unorthodox and flexible. He lets the material contribute to the design and form, rather than discarding the material or attempting to force it into a preconceived mold. The exercise of ingenuity and the challenge that goes with the utilization of waste materials can be a dominate motivation to the artistic personality. People put down the local scavenger as one "scabbing on the system," but the scavenger challenges the system as wasteful of natural resources. It is not a comfortable reminder that our American 6% of the world's population devours 35% of the world's annual production of raw materials!*

There is a tendency of people who ha
act in such a manner that it utilizes a
trying to scare you into adopting the
design scientists, watch yer parking m

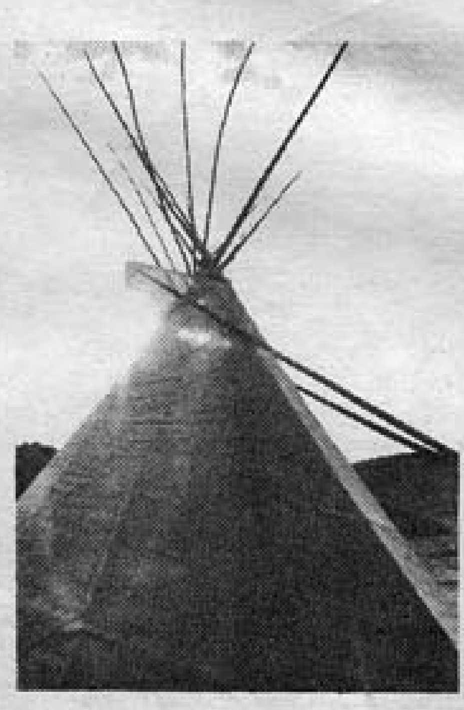
I've been a guinea pig with plastics, e
migrate, airborne into the dome. If y
give it the acid test; get stoned, look

I recently read that soldiers in Viet N
transfusions that come out of plastic
plastic flexible) gives off molecules,
the bloodstream.

Plastic is not in itself evil, but use i
from, what it feels like, who is telli
with plastics over the past few years
Vinyl turns out to be utter horror, n
used in its production. It gives off g

Plastics are super products of wester
Hucksters delude the American publ
oil:big hungry cars/plastic pin curler

Don't be afraid to use plastics, just b

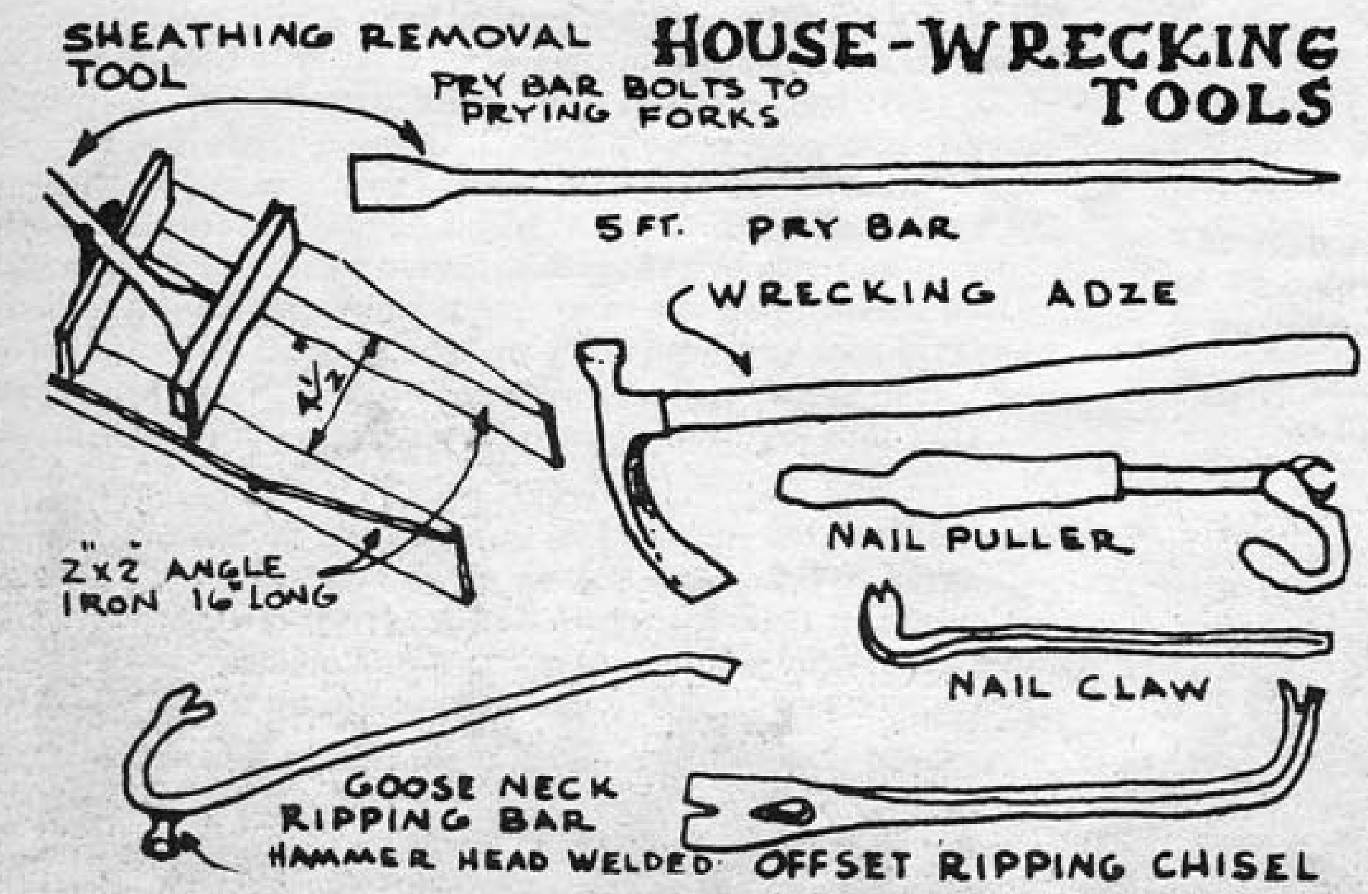


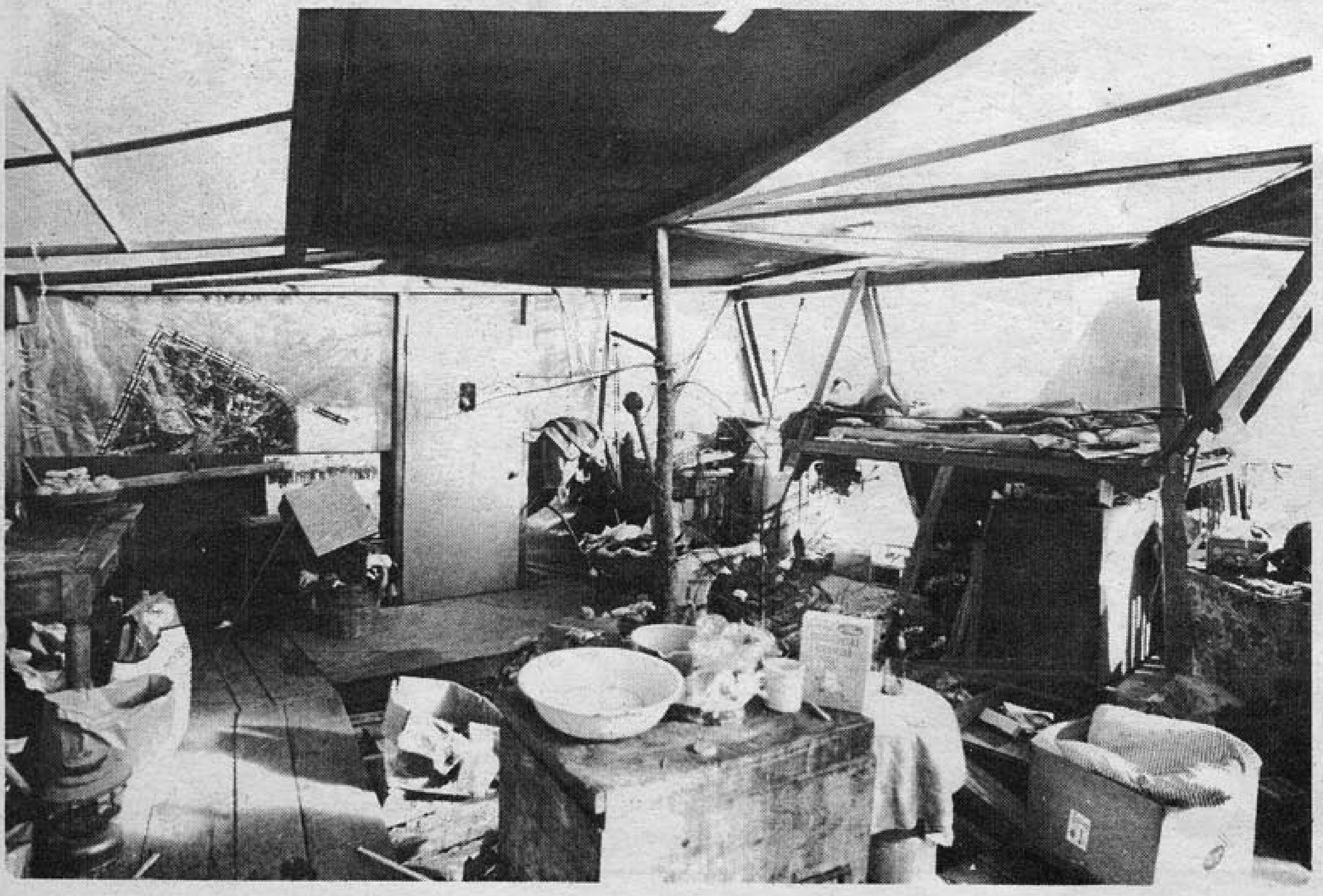
In San Francisco Chinese merchants put out their garbage on Wednesday nights, which always includes many wooden boxes with Chinese lettering. Also an occasional soy tub.

Clementina trash service has 8' X 16' boxes they leave in the San Francisco streets for contractors to load up. In residential areas wealthy people have contractors tear out fine old wood doors and windows and replace with aluminum sliding doors and windows. You can get 2 X 4's, doors, hinges, whole windows from these boxes, the contractors are usually glad to have you remove their garbage. Once we got 30 doors out of a box.

Bernard Maybeck, wonderful San Francisco architect of early 1900's built a house with walls made by draping gunny sacks dipped in lightweight concrete over wires. When concrete sets, rigid wall created.

**LOOK...** If you move into a new area ask the old timers what there is around to build with. Find out where used materials are, where there might be some abandoned buildings. Here at Zaca Lake, where we're putting this book together there are a lot of rocks, so it would be natural to do something with rock, at least a fireplace. Down the valley on the way to the highway, there's a dilapidated shack, beautiful wood. Just look around you. Don't worry as much about efficiency as resourcefulness. Don't worry about how much your building weighs, it doesn't have to fly. If you live near a big city, there's an entire house waiting right now in the streets, ready to be picked up.



*Building materials are everywhere! Discounting the natural elements—earth, rock, trees—one can find salvage, culls, dunnage, scrap, junk, and surplus items wherever you might look. One needs to learn the fine art of scrounging: keep an eternal eye out for materials. Haunt the junk yards and auctions, acquaint yourself with local building material industries—"culls" and "brokens" and "number twos" and "discontinued lines" are common occurances in any high speed factory production. One can secure these misfit materials sometimes free for the hauling off. Plumbing fixtures with unimportant "hair-line" cracks are commonly available at half price.*

### ...THE FINE ART OF SCROUNGING

*The serious scavenger makes as his first investment an oxy-acetylene and arc-welder. Scrap metal is relatively cheap and universally available; used corrugated iron can be re-worked to meet a multitude of building needs; 55-gallon oil drums and iron pipe are low in cost, easily worked and versatile. Metal products are commonly available free at the local city-dump. Public dumps are also a good source for broken sidewalk pavement—which can be reused for walk and patio paving and for retaining-walls. Telephone and electric service companies often have used poles for sale; railroad companies sell used ties cheap. Packing crates can be salvaged with little effort; plywood panels are often used for crating...*

FROM KEN KERN'S *OWNER BUILT HOME*

o have a bag to tell you that there is reason to
es aforesaid bag. Watch self-styled leaders
their solutions. Watch out for grand designers,
g meters.

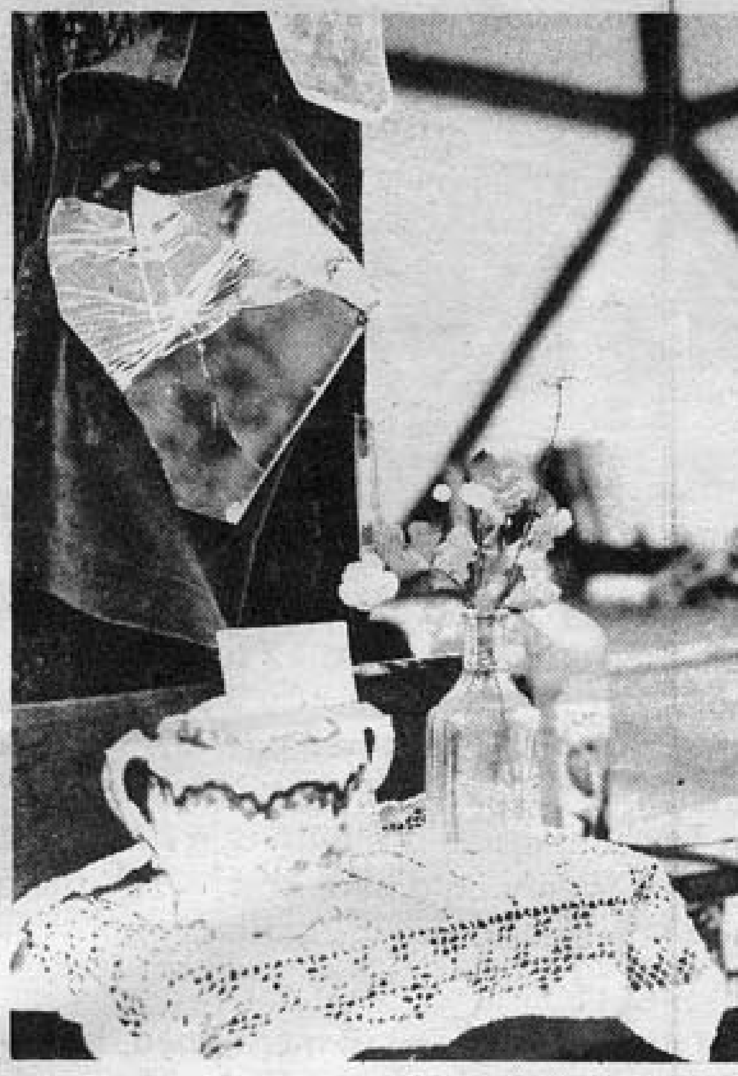
s, especially vinyl. The plasticizer molecules
f you're thinking of building a plastic dome
ok hard, breathe deeply, feel the stuff.

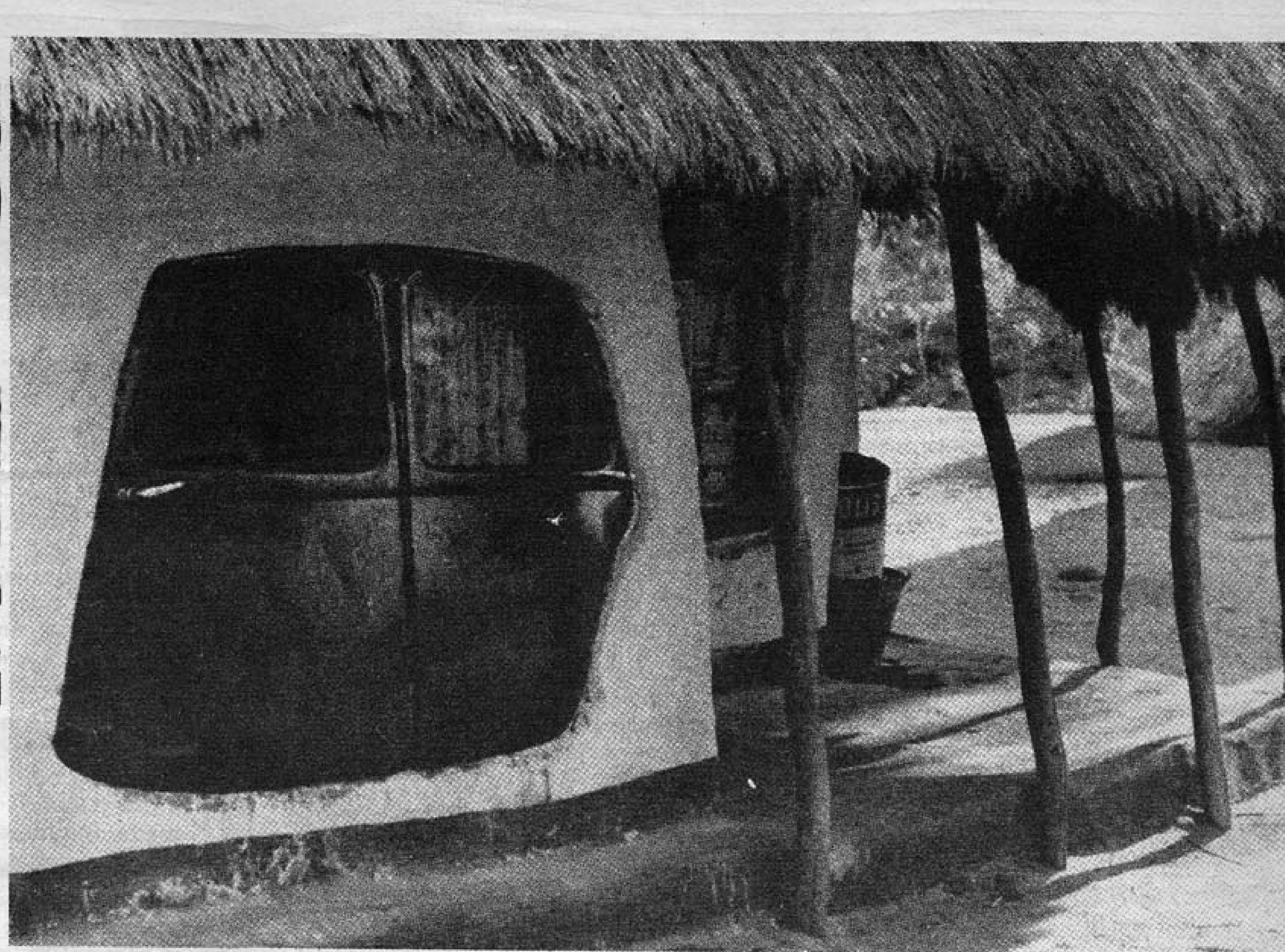
t N m are dying occasionally from blood
tic bags. The plasticizer(which keeps the
s, which in this case, presumably got in

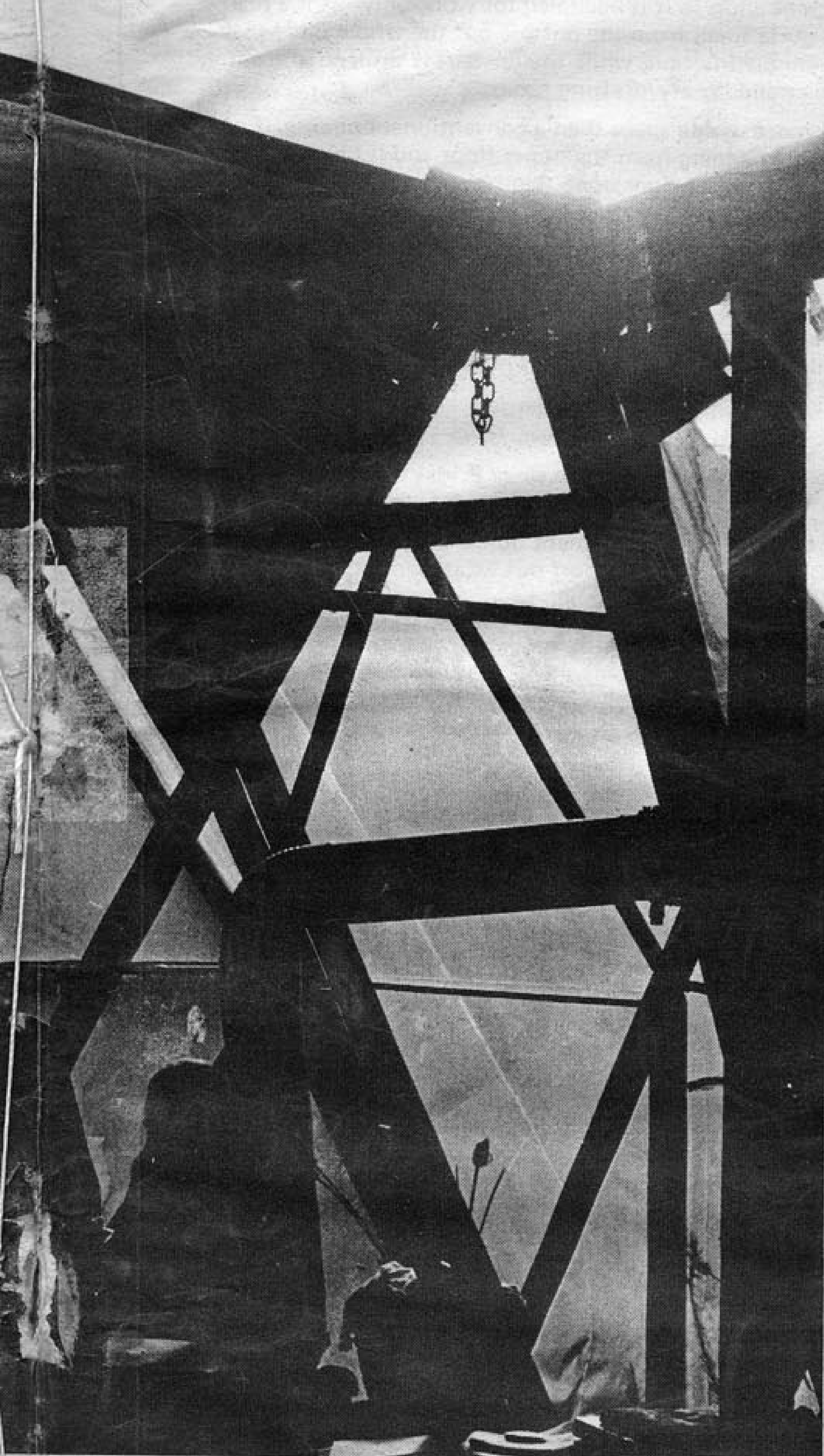
it with full knowledge of where it comes
ing you to use it. I've experimented heavily
rs, now find myself backpedaling furiously.
. maybe it's something to do with the mercury
gases when the sun hits it.

tein oil man sucking the earth dry of petroleum.
ub it into demanding products made from
ers/plastic wrapped food.

t b ware/beware.







## THE ONLY GROWING RESOURCE IS TRASH

You can split up short pieces of wood for shakes. Most common material is cedar or redwood. Loggers usually leave a mess behind, including short pieces of wood that can be split into shakes. Windfall trees are also good. You can also get shakes out of railroad ties, I've made them out of old redwood highway markers.

If you find a condemned or abandoned building you can often arrange with the owner to tear it down and clean the site in exchange for the salvaged materials. If you can find a saw mill that will saw used timbers, you can make use of heavy pieces. Mills are usually afraid of nails wrecking a $400 saw blade, but you can sometimes talk them into sawing timbers if you're careful in removing all nails.

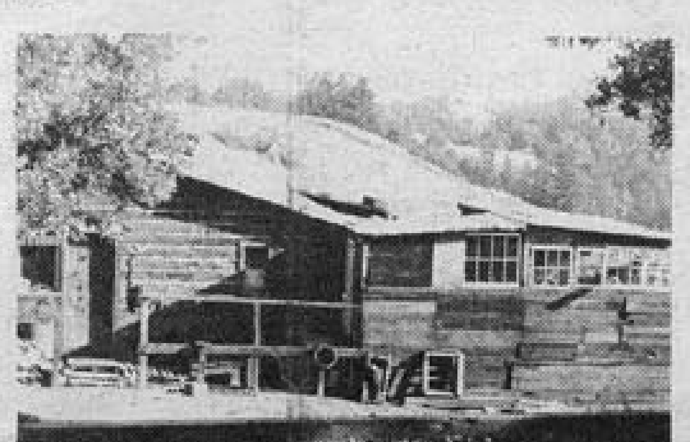
Bob Easton is using old 2 X 4's for struts for his domes in Santa Barbara. The old lumber is so hard carpenters can't drive nails in it, so it's not good for conventional building.

Look up in the phone book: wreckers/salvage/used wood. Wrecking companies have doors, windows, tubs, fixtures. Old phone books, newspapers with resin could make panels...bamboo/beer cans, bottles...old phonograph records...stucco: cheap, Bob uses it with small amounts of wood.

Aluminum plates used by offset printers could make a dome. Plates about 2' X 3'—high frequency dome. It's flimsy, but could be shot with foam, 7¢ per lb, can cut with scissors—from Rob Nerins. Cardboard refrigerator crates at appliance stores.

*Somewhere in the middle of taking all these pictures we realized that we were showing the best side of things: a dome in the forest, sunlight shining through tree branches, rather than the junk underneath the dome. A plastic dome glowing in the field at night, rather than the poisonous gases produced in converting petroleum to plastic. After realizing this I looked at Life, Newsweek, realizing that they're doing the same thing, writers, photographers show one side. We're still doing pretty much the same with this book. Taking the best pictures, using what's most beautiful and instructive. What most closely corresponds with the vision. As you read, keep in mind it's not as pristine, simple, clean as it appears. There's a danger in the hype, overromanticizing domes.*

## SHELTER



We're aware that scrounging materials can't be a solution for the planet's housing problems. But it's thinking that way, learning how to make do with what's around, that kind of trip that gets your head in the right groove. People who will be in charge of mass production, if that happens, ought to have a background building with garbage. America isn't going to produce lightweight portable plastic geodesic domes for Africa or India, that's a fantastic delusion and ripoff. These countries should be building with what they have.

We don't need a prime designer. People that are out of work need housing. Employ them by letting them make their own shelter. They can do it themselves, by using this book, or we'll come help them get started.

# STONE DOMES

In *Domebook One* we printed brief instructions on ferro cement boat building, hoping someone would try the technique on domes. Several months later, we received a letter from Norval, Russel, and Marvin Jensen, father and sons, with details on a 38' ferro cement dome built on their farm in St. Ansgar, Iowa. In addition to the letters from the Jensens, we are also printing parts of an essay on ferro cement by Derek Van Loan, a Sausalito boatbuilder, and excerpts from a review of the subject by Bill Chaitkin, who is half-way through a ferro cement project in Syracuse, N.Y. To get full information on ferro cement over a steel framework you should read both Van Loan's and Chaitkin's articles, as we have eliminated duplicating portions. The Jensens describe a ferro dome on a wood framework, which sounds much easier than the metal frame, in which the frame becomes part of the structure—as with boats.

Ferro cement is hand-done, as opposed to spray-foam, which requires heavy and expensive machinery. It takes a great deal of time, but perhaps, as Neill Smith has pointed out, our structures should be built of the least amount of materials, with the greatest amount of time and care. The raw materials of ferro are produced with relatively little pollution, and silicone is the earthsurface's most abundant element.

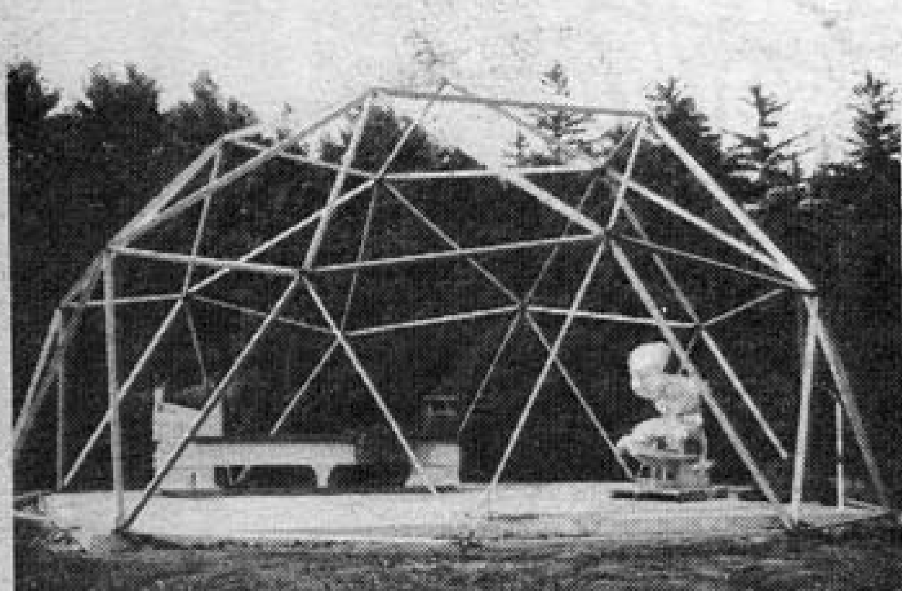
## JENSEN DOME

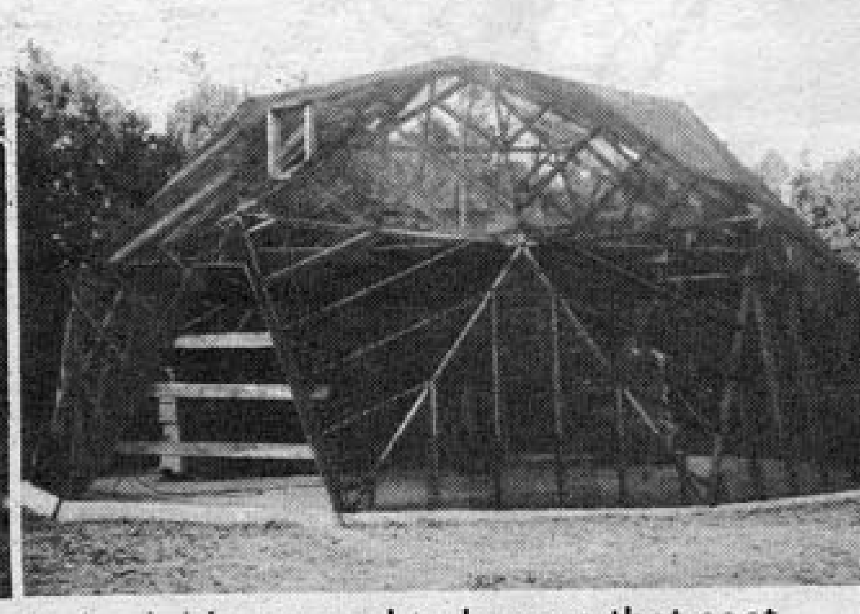
*unsealed ferro cement*

Dear Sirs:

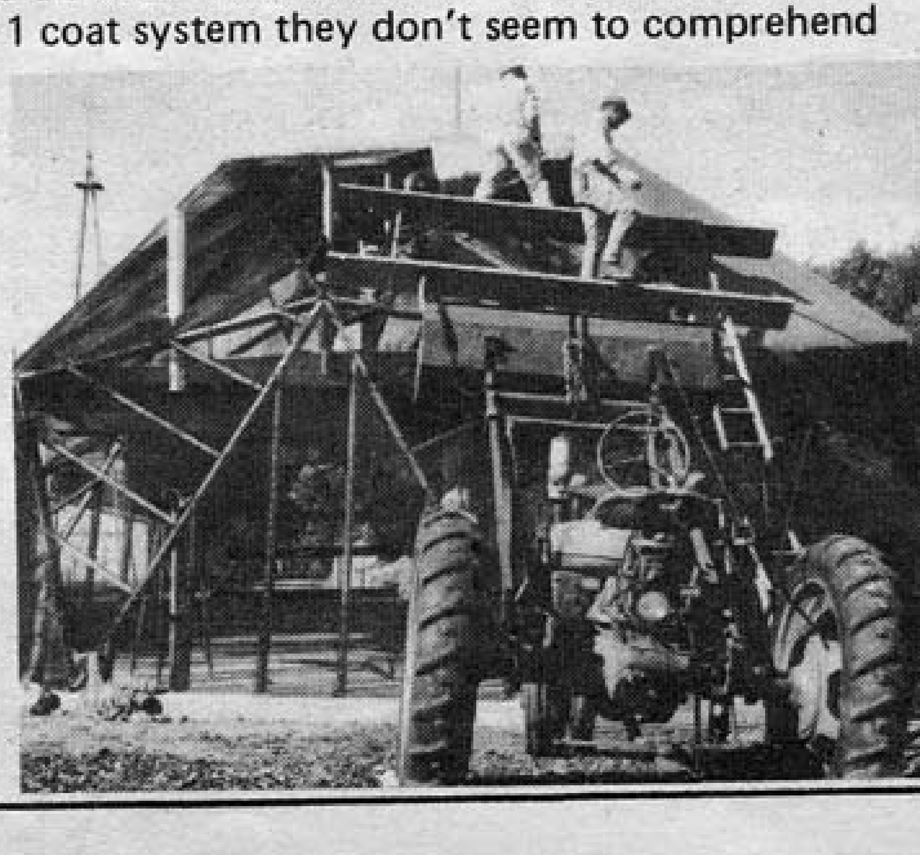
As per instructions on inside fly of *Domebook One,* enclosed are some thoughts, discoveries, criticisms, and what it's like living in the new space; although not necessarily in that order. First of all we found your book most helpful for both ideas and more important on the practical side the super formulas in the back of the book, although they could be used much faster if a little more instruction accompanied them, i.e., it took quite a while to get it together on the angles at the hubs, which wouldn't matter to most domes but with our construction it made a lot of difference....

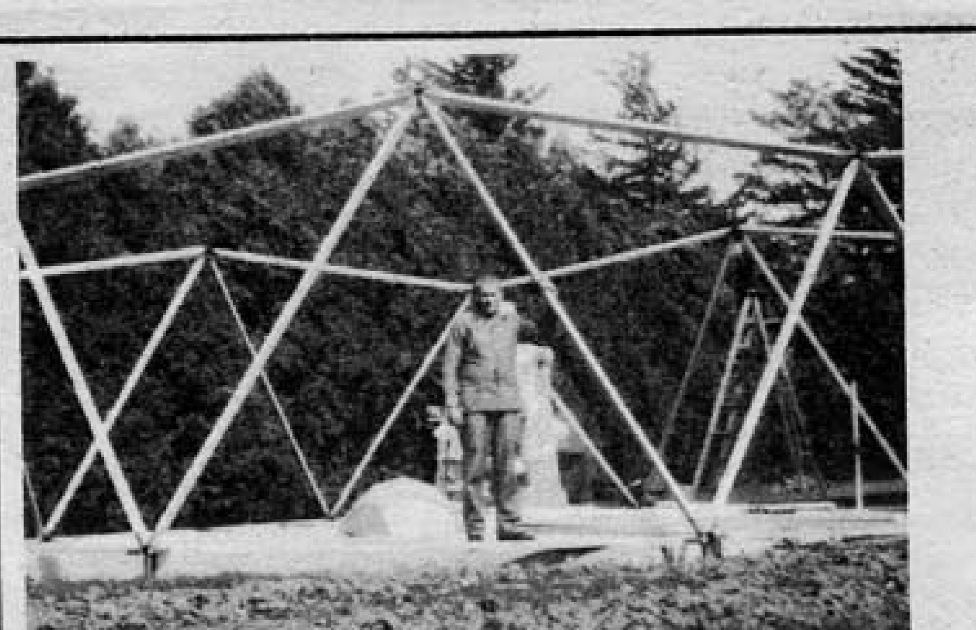
The next thing that was nice about your book was p. 43, the ferro cement idea. We put 2 ft centers in the triangles and covered it with a layer of metal lath, 2 layers on top and proceeded to cover with cement. After checking with local cement plant it was decided that No. 1 portland was satisfactory for a building, we hope it isn't subject to salt water. We used a No. 4 grade of sandblasting sand in the approx. blend of 1 bag No. 1 portland (94 lb) to 2 bags silica sand (200 lb) and 6 lb hydrated lime. Mixed in a motor mixer. We hired an old plasterer and some neighbors, unless you're good the plasterer (if he's good) is the only way to go. We started on top carrying the cement up to him in buckets and he





put it on with a trowel, with somebody inside to back him up and to be sure that coat is complete. Hindsight is of course better and the next one will get a layer of fine screed and then 2 layers of lath as there were problems of cement running through (or crumbling through depending on how wet or dry each bucket was, depending how much water was used to rinse bucket between loads). The moisture content is real critical! The single lath was a real bummer. As triangles were completed (2 plasterers working on both sides so as to try and get done in one day Ha Ha!), they were sprayed with a cement sealer to prevent drying. The inside wasn't sprayed as it was given a plastering to insure seal of mesh so it couldn't rust. It took 3 days to finish job, top ½ was done first day in one coat and bottom ½ was single layer mesh and required a scratch coat and final. Old plasterers have to be convinced as they don't believe in the 1 coat system they don't seem to comprehend the single coat is for strength.





I don't know where the 24-1 ratio on p. 49 came from as we greatly exceeded this with a 2-frequency dome 38 ft diam. It held 12 tons of cement till cured without any sign of give. Of course now that the cement is dry we could take out 2 X 4's but you remember the 2 ft centers, they also came in very handy for stapling insulation to, before the insulation was installed a 100,000 BTU heater ran continuously and it got down to 0° outside and about freezing inside but with 3 in fiberglass insulation it is heating for about 75¢ a day and it is very cold here now, −26° the other day. The dome was sealed with a concrete sealer before insulation was installed, this sealer was white and gives a nice appearance to the structure.

The interior was of course insulated as mentioned, but with an aluminum foil backed insulation which is the finished surface which aids greatly in the lighting of the building. This building is used for a machine shop so it is occupied for work only. It is a real fooler of a building as it looks quite small from the outside but the whole 38 ft span of the floor is clear and free from obstruction, while the upstairs is suspended from the roof, it is used for electronics and library/drafting room.

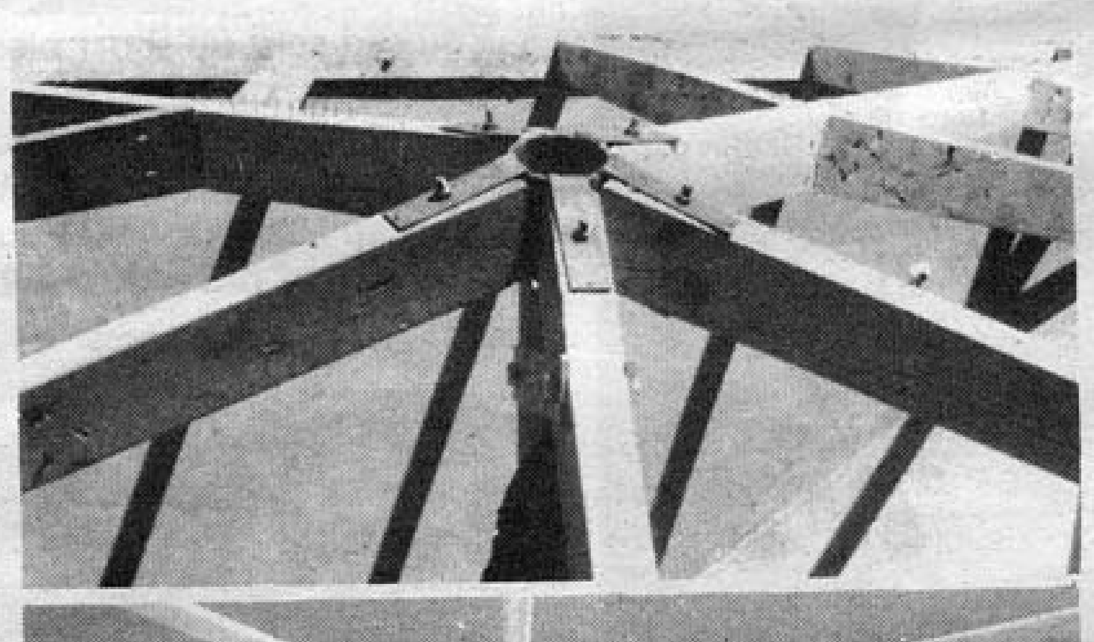
This dome design has so much more usable space than a conventional building. For heating we have a resnor lp burner hanging from the upper floor and it blows around the dome. With the stairway to the upper floor open there is surprisingly little difficulty in heating, upstairs and downstairs, the temperature is maintained from 68 to 71 degrees (probably cold for a house but nice for a shop). I have air conditioning installed but will have to wait for summer to see what it will be like. We are very happy with the dome...

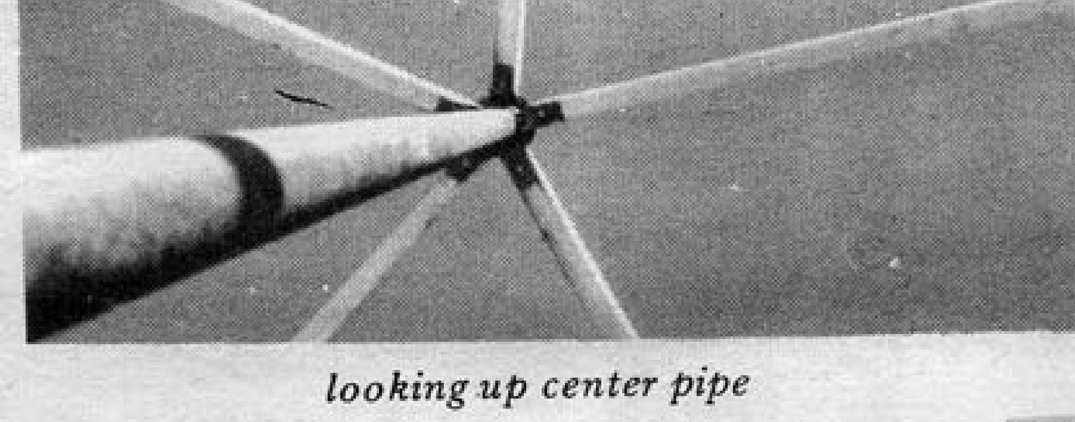
Oh yes the dome is already tough as we have had two 12" snow falls which took down roofs on quite a few metal buildings in area, dome shows no sign of giving any...

Russell Jensen
St. Ansgar, Iowa

Would have answered sooner but have been snowed in since Friday—may get plowed out today.

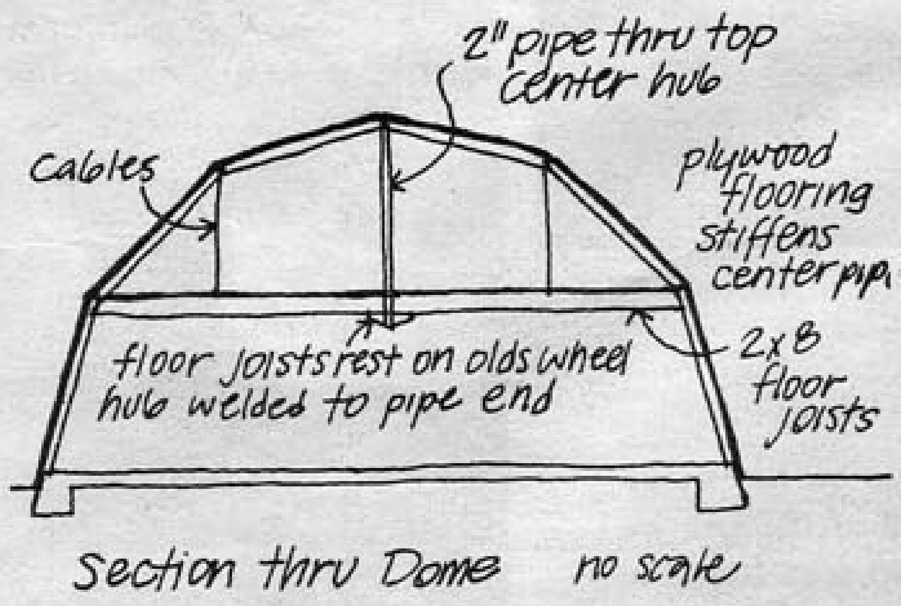
Enclosed find a breakdown of cost of the ferro—cement dome. Another building was being built at the same time so it was a little difficult to sort out what went where, however this list is very close. Some things aren't reflected, i.e., welding rods, steel strapping, nails, electricity, as these items were on hand or impossible to separate from items used in other building.





*looking up center pipe*

| | |
|---|---|
| Floor (extra heavy) | $700.00 |
| Metal mesh | 450.00 |
| Silica sand | 100.00 |
| Covering cement | 110.00 |
| Cement sealer | 25.00 |
| Labor (plasterers) | 340.00 |
| Rent on mixer | 20.00 |
| Lumber for frame, stairway and 2nd floor joists | 250.00 |
| Lumber for large triangle door | 30.00 |
| 3/4 plywood for 2nd floor | 185.00 |
| Doors and windows | 26.00 |
| Drylok (exterior paint/sealer) | 90.00 |
| Paint for 2nd floor doors and windows | 70.00 |
| Pipe, cable, bolts etc. for suspending 2nd floor | 20.00 |
| Insulation and staples | 255.00 |
| TOTAL | $2671.00 |




Section thru Dome   no scale

The bottom floor has 1100 sq ft while the upper has 700. The upper floor has a 30 ft diam. while the lower has slightly over 38 ft. On the upper floor there is a 22 ft diam. where there is sufficient head room to walk leaving a 4 ft strip around the edge we are using to stack things.

*finished dome with white sealer*

To take the shake out of the lightweight floor (2 X 8's—for ridge floor should be 2 X 12's) cables were brought from 5 hubs to floor.

Now beside taking shake from upper floor for upper floor to cave in, center hub must pull in making 5 connecting hubs bug out. Cables will lift harder on floor cancelling any tendancy for floor to collapse. After cement dried it seems like a lot of wasted effort (the cables) but it does help keep upper floor stable.

P.S. It doesn't seem logical that the dome took that much lumber but the 2 ft centers ate up far more lumber than was in the frame of the dome itself.

Russell Jensen

# THIS IS WRITTEN...

Derek Van Loan

This is written to spread technical knowledge among humanists, reduce competition between individuals, and establish a new aboriginal way of life.

This is written for the abject scrounger about a way of combining materials as common as concrete and steel to make a new material that's better than any plastic. This material is Ferro-cement, and it will be the nucleous of new industries and it is the nucleous of a new way of life.

Ferro-cement was named "Ferro-cemento" by Pier Luigi Nervi, who discovered the favorable strength and flexibility relationships of lots of finely subdivided, steel-reinforced, concrete. Ferro-cement is a proven material for building boats. It is also suitable for homes, watering troughs, and underdeveloped peoples. Although Ferro-cement is suitable for building a house shaped like the landscape or a pagoda, here I am mainly concerned with boat hulls; the techniques of building and designing and transmitting the design for houses can be similar to the same techniques for boat hulls.

**Material**

The warm feeling has been developed by man over the centuries for wood and stone and iron that man will develop for ferro-cement. We are at the stage where the technology of the stone age and the technology of the iron age are united in a new material, ferro-cement.

Ferro cement differs from reinforced concrete, which was used for ship construction during the two world wars, in the amount of steel reinforcement, and its subdivision, the density of the concrete, and method of construction.

The old concrete ships were cast concrete and the new ferro-cement ones are a stucco method.

Perhaps the greatest advantage for Ferro–cement is the lack of tools and lack of skill necessary to achieve a strong if not finely finished boat, although a finish as fine as fiberglass or wood is obtainable.

There's got to be a balance between doing and thinking. Our method is to do. If all is not known about the material or method, it doesn't matter; there will always be different ways to build as there are different ways to build boats now. Schools have taught us to over intellectualize.

It's really hard to mess up a Ferro project—we tried to make a weak boat, we used a 1 part cement to 1 part sand ratio, cured indifferently for 6 days, used no rod except around the gunwale, didn't penetrate well in places, anyhow it works, good too.

**Cementing**

Don't let cement experts talk you into using any fancy 28 chemicals, you don't need them.

Gather tools: mortar mixer (paddle type), rent $7.50 per day, electric if possible, and if you have electricity, the gas ones are noisy / goggles / hand cream / hats / gloves—water proof heavy duty / trowels: big rectangular ones to stop cement as it comes thru mesh; one or two pointed ones for cramped spaces; wood floats; sponge trowel (gives surface which can be easily sanded) / buckets for carrying and measuring water, dry cement, mortar, sand and dirty mortar / tape, paint, grease pencil to mark buckets / scales (bathroom) / wheel barrow to dump mixer into / hose / shovels / ladder / lights / extension cords / vibrator box (see sketch, you have to make one yourself) / pencil vibrator (rent) $3.50 per day / sheet of polyethelene plastic and burlap to go over hull after it sets / *food*—spaghetti is traditional. Have ready for eating at all times so work doesn't have to stop completely for meals. Have more than enough. Lemonade, coffee, and milk are good for drinks. Alcoholic drinks might produce a congenitally misformed boat.

The sand should have an even grading curve, that is it should have equal amounts of very fine, fine, medium and bigger sand particles. The sand should have No. 50 minus up through No. 2 sized grains. There should be no clay in the sand. There should be no excess of any one sized grain. Use 2 parts of dry sand to 1 part cement by weight. Look at the sand with a magnifying glass, and compare it to other sand. The sand is the strength of the concrete, the cement is merely the glue that holds it together. The sand should be sharp.

Type V cement (25' boat 22 bags min. 35' boat 55 bags min.).

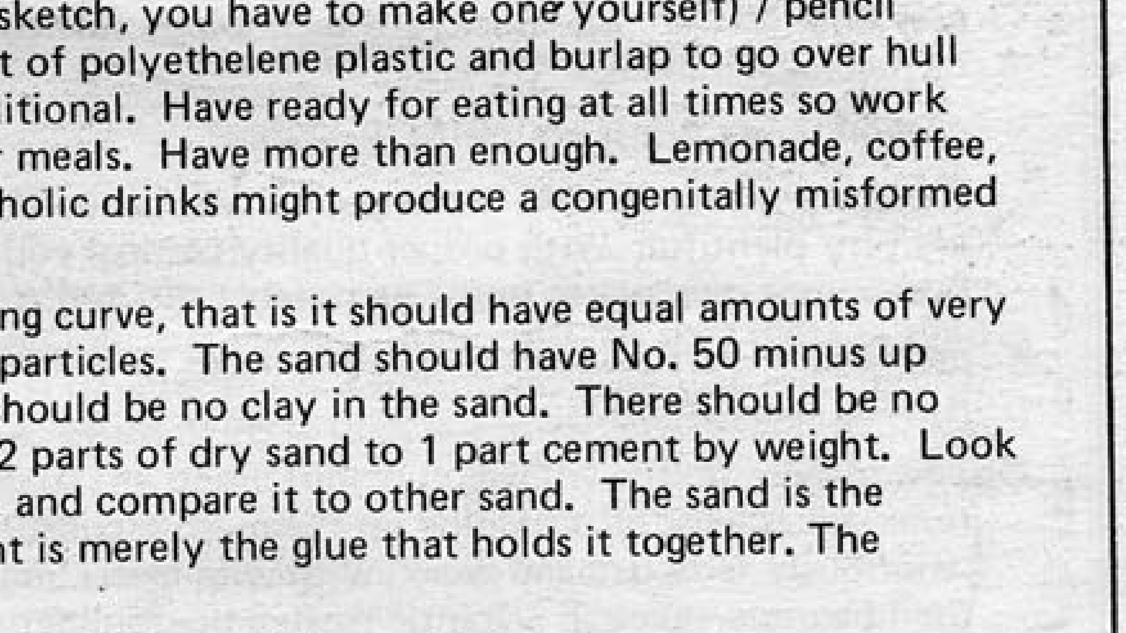
At present the main line of F.C. school of thought runs to cementing the whole hull, at least, (deck too if possible) in one continuous operation. By the time that you get ready to cement the boat hull you may think that you are an expert. Unless you have helped cement a boat before, you aren't. Even then you aren't.

Get all or most of the above junk together before even starting to think about cementing. Choose a windless day if outside, sunless too if possible. Get a bunch of people that you would trust your life to. Explain to them that perfect penetration and encapsulation by the mortar of the mesh and rod is where it's at, and that you want them to push mortar thru the mesh and rod from *one* side only. The whole job will take many many hours (18-20 for a 36' or with 600 sq ft of surface, 25 people working).

Two people should mix mortar and two should carry mortar from mixer to hull.

Wet all the mesh with water before plastering, it is said that this aids penetration. Have the mixer away from the boat because it's noisy.

First put the water into the mixer, about 3½ to 4 gallons per bag of cement. Next add the sand, two times the weight of the cement (188 lbs). Then add the cement (94 lbs). Add more water if necessary, but remember, the vibrator will make even a very stiff mortar flow. Let the batch mix for 5 minutes or so (don't put your hands into the running mixer). All the particles of sand should be wet and the mixture should be plastic and hold together. Pour the mortar out of the mixer into a wheel barrow and then use a bucket to fill the vibrator box.




*Sam Presley's Vibrator Box. Vibrating cover forces cement thru mesh like hypodermic needle. Start box at top and move down. Men inside stop cement with trowels and check penetration.*

The vibrator shakes the mortar so that the particles separate by their weight into big and little particles that don't interlock and the mortar flows. Have trowels big enough to back up the vibrator box and stop the mortar as it comes thru.

Vibrating cover forces mortar thru box into mesh like hypodermic needle. Start box at top of hull and move down. Overlap 3" or so. Men inside stop mortar with trowels and check penetration.

One person should check all the work, and have only checking to do.

The mortar starts to form crystals when it is mixed. Ideally the mortar should be disturbed as little as possible so that the crystals can grow to be big and healthy and strong.

The less water the mortar has, the more dense and closely packed the mortar will be, and the less shrinkage there will be when it sets up. Shrinkage causes cracks and causes mesh to pop out of the finished hull (not enough water to wet the mortar would cause the crystals not to form and makes a crumbly mortar).

Don't play around with it. Even if you work constantly plastering takes long enough. Work steadily.

Important: don't start several areas of mortar. It is possible by using a wetter mortar to plaster the hull by hand with gloves. It goes about as fast as plastering with vibrator box, but some plastering will have to be done from both sides greatly increasing the possibility of hollow places (voids) in the hull. There is also the possibility of greater shrinkage and mesh popping out of the hull. Many good hulls have been built this way however.

**Finishing**

Have someone finishing follow right behind the people operating the vibrator box on inside and outside. Leave 1/8" of mortar covering the mesh. The outside finisher should use a wood float (1½ to 2 ft long) sparingly to cut down big hills of mortar and follow with the sponge trowel which leaves a rough surface which can be easily ground down by hand with "holy" stones made for cement finishing. The inside finishers should scrape the mortar off down to the mesh with steel trowels. If you want a place on the hull extra glass smooth, smooth some polyethylene plastic over the wet mortar, and peel after curing.

If any of the mesh is sagging it can be propped from the inside of the hull. When you are finished cover the hull with polyethylene (one big sheet if at all possible) to keep the moisture in. The next day begin gently spraying with water and cover with damp burlap bags or old rugs. This is curing and should be done for 28 days. After the first 3 days you can very gently holy stone grind the hull, but don't put any weight on it, and keep it damp.

**Coatings**

One of the most successful coatings we have used is epoxy glue mixed half and half with cold roof tar (plastic asphalt cement). Standard marine paint works good on cement but if the surface is rough the paint will cover 1/3 as much as the can says it will.

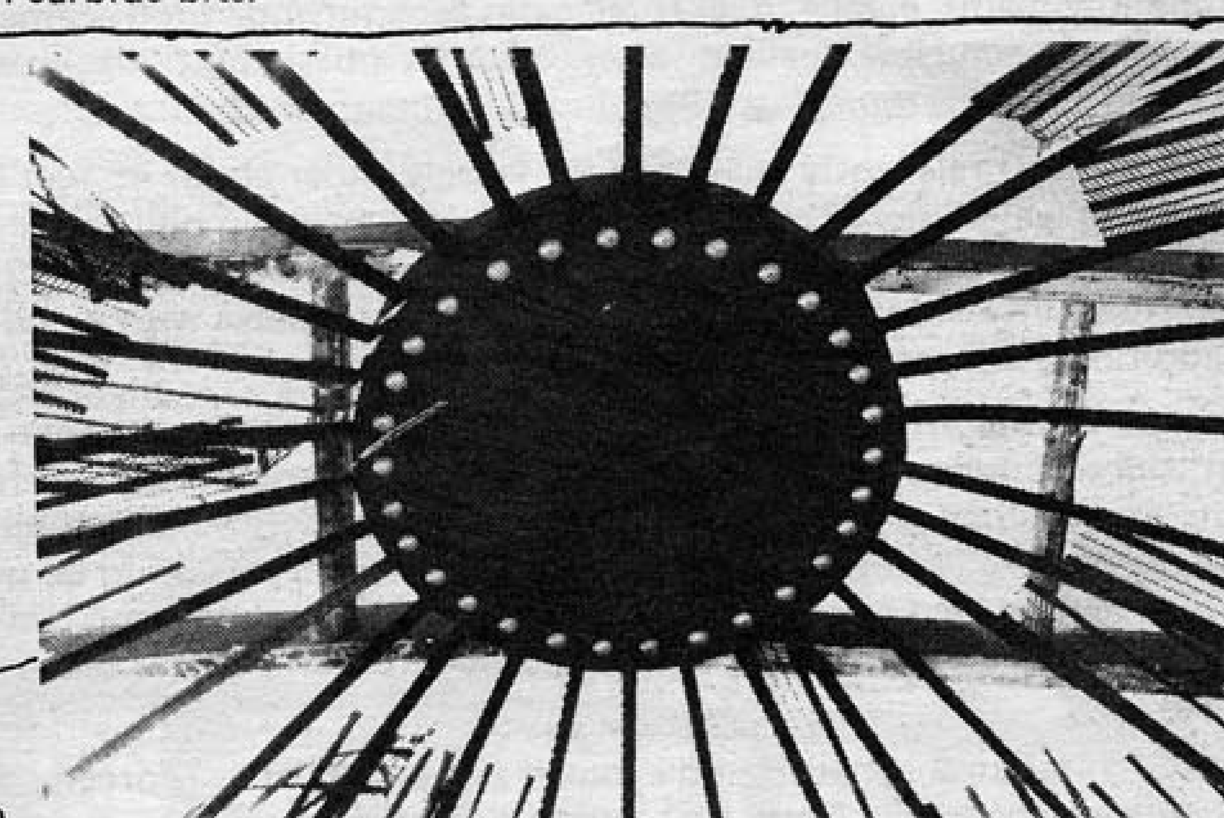
**And**

Gunite, a method of spraying cement through the steel reinforcement used for constructing swimming pools, has not been proven for Ferro-cement yet but looks promising for people with money or the ability to build a gun.

Repairs can be made by bending the damaged section back into shape, beating out some of the old cracked cement and smashing through some fresh cement mortar. Damp cure for 28 days for full strength.

Windows can be put in by leaving a hole for the glass and cementing in the glass after the hull is built.

Ferro-cement can be drilled using the same spring steel rod used in its construction. To make a drill bit: heat length of rod dull red, in gas stove flame or butane torch flame, flatten with hammer, sharpen to a triangular, blunt, point, with a grind stone, and re-heat the sharpened end to cherry red and plunge it into water. If you drill into a rod in the Ferro-cement aim the bit around it. Make several bits at once as they dull fast but are cheaper than carbide bits.



Following are excerpts from a letter from Don Patterson, a boat designer and builder.

...Here are some views and general principles of Ferro-cement dome design.

1. Materials — Cost - Low, compared to wood and plastics
2. Strength — High but weight also high. Ferro-cement is decidedly poor in its strength to weight ratio when compared to wood fiberglass, steel and aluminum.
3. In dome construction the use of light weight aggregate is more feasible than in boat design since permeability requirements are less stringent. Contact the Expanded Shale & Clay Institute who will provide you with technical information in its use, etc....

Hog rings are the thing... current best method for tying mesh to rods. They can be obtained from any upholstery tool suppliers. Use ¾" or ½" hog rings depending on the size of rods.

Compressed air driven Hog ring gun from Power Line Co. Limitation is not quite 100% clamping but placement of ring is FAST. Better than wire tying/no loose ends/quicker....

Expanded metal is cheaper than other mesh in terms of weight of steel but poor in penetration access — poor in compound curves....

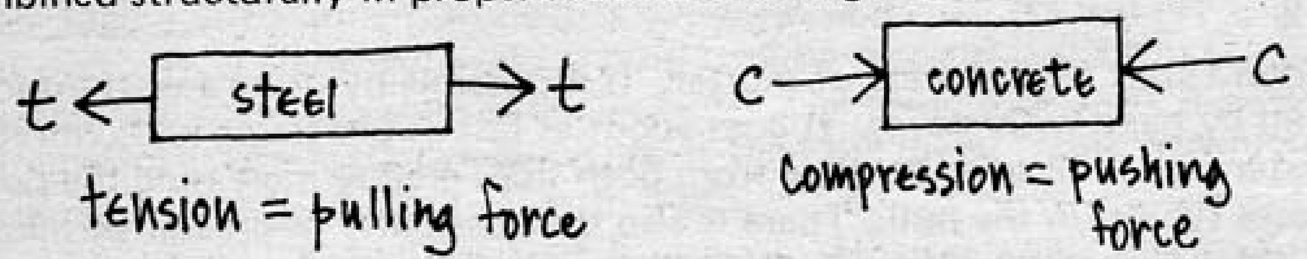
Don Patterson
DSD Boat Design
Leucadia. CA

# FERROCEMENT

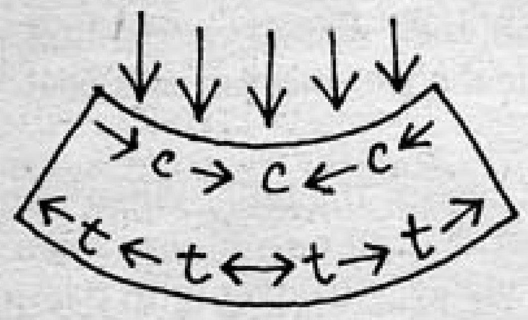
Bill Chaitkin

**Theory and History**

The term *ferrocement* is self-defined by its material components, ferro = iron (or steel) and cement = concrete (without the usual gravel aggregate). However, accepting Fuller's proposition that there are in microcosmic reality *no materials,* only structures (systems of energy events), it might be clearer to explain it by its structural behavior. The principle is identical to that of reinforced concrete, whereby the concrete, a chemically-bonded mix of water and Portland cement (Portland cement is not a trade name but a generic term for a manufactured ingredient of concrete.) To avoid confusion, remember that subsequent use of the term *cement,* as in ferrocement, means just concrete-without-gravel, and thus cement includes Portland cement but isn't the same thing.), with aggregate for body, resists compressive forces, and interacts with the iron or steel reinforcing bars which take the tensile forces. Thus each component material does what it is best at, and when combined structurally in proper ratios and configurations works synergetically.




The difference between reinforced concrete and ferrocement is a matter of scale; ferrocement consists of less concrete to more steel, and the concrete has only fine aggregate, and sand (gravel = coarse aggregate), and the smaller steel members are more evenly distributed throughout the concrete mass, so that the local interactions between steel in tension and concrete in compression multiply in proportion to the increased surface area of the steel. Obviously then ferrocement is more efficient, pound for pound, than reinforced concrete.



reinforced concrete beam in bending: when loaded, it is as if the top were getting compressed shorter while the bottom is stretched longer; thus the steel goes along the bottom.

This is why ferrocement boats are so "strong", but remember that by strong we really mean flexible or resilient. The remarkable thing is perhaps not that we can make a ferrocement hull that will split rocks upon which the boat is driven, but that we can make a ferrocement *diving board,* just as springy as wood. The rock is rather like unreinforced concrete with no steel to give it tensile strength, so that however hard, it is brittle, like diamonds.

Unreinforced concrete can be pulled apart much easier than it can be crushed. This may, be verified by your own experience, and conversely if you've ever watched or attempted demolition of a reinforced concrete structure, even a sidewalk slab, you know that unless the steel is cut, nothing will unhinge it.

It is more useful to deal with these structural properties than to regard ferrocement as some magical material, indestructible as Kryptonite, which cannot be demolished.

Ferrocement members act most efficiently as monolithic "thin-shell" membranes, not beams, and these membranes not only need not, but can not, be more than about one inch thick, lest the dead weight of cement reduce efficiency beyond a point of diminishing returns. So to make it "stronger" add steel, don't just increase thickness.

The history of this composite material is better dealt with elsewhere, but of recent experience from which we might profit ferrocement technology has included (A) boats and (B) buildings:

A. Ferrocement boatbuilding is currently very active on the west coast and elsewhere in the U.S. both for utilitarian fishing craft and pleasureboats, even sailing yachts, while thousands of ferrocement working sampans have been built in China. Economy, durability, and low maintainance in all these cases recommended ferrocement. Leading in development has been New Zealand, whence comes a basic text: Jackson and Sutherland's *Concrete Boatbuilding,* 1969.

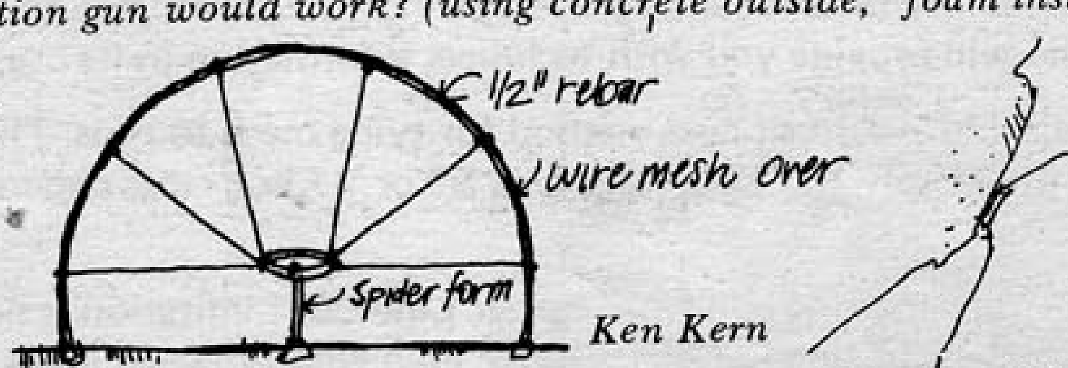
The authors note most relevantly that only for vessels under about 45 feet long does a ferrocement hull weigh more than a comparable steel or wood hull, while ships over 100 ft long cannot be structured as thin-shells but must use conventional concrete reinforcing. Thus between 45 and 100 ft ferrocement competes with wood and steel, and offers additional advantages over them.

Fuller, in *Ideas and Integrities,* makes a morphological connection between hulls and domes. Yet, since building on land involves less critical tolerances and performance requirements, the analogy is imprecise but still informative. If a hull, structured to withstand its dynamic environment, were inverted as a dome, it would be overdesigned for the relatively static land environment. In fact, land-bound building technology in general has always lagged behind that demanded by structures of the sea—and more recently, of the air.

B. Ferrocement architectural construction evolved as a subset of reinforced concrete. The Italian engineer Pier Luigi Nervi first experimented with what he named *ferrocemento* in the 40's, using thin, light, precast members for corrugated vaults, ribbed domes, arches, and space frames, often of great span. Nervi also built large ferrocement boats, but contributed more perhaps to investigations of structural forms unique to that composite material, as boat hulls (or domes) are not.

*Looks like I'm into domes now! The O'Neals ranch I mentioned in an earlier letter is forging ahead—ready now to try a prototype. We worked out a "spider" form from which rebar is anchored—then lath or wire applied and foam sprayed. I wonder if the portable application gun would work? (using concrete outside, foam inside)*

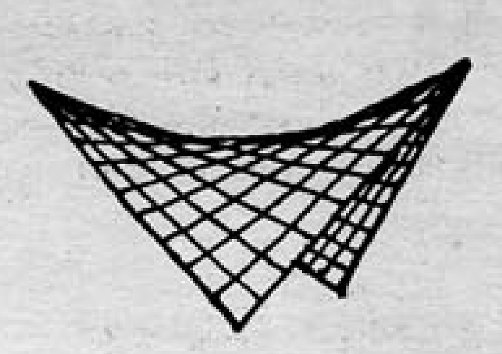
*Any comments?*



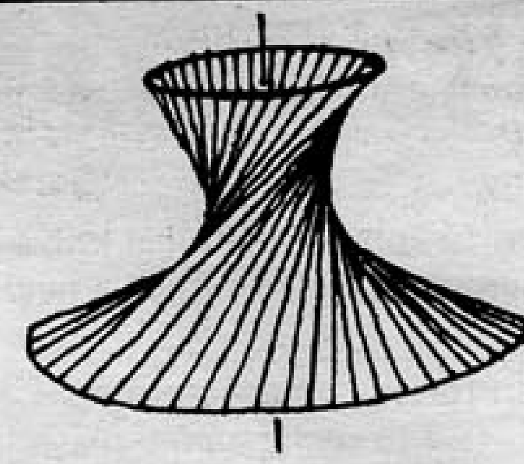

*Ken Kern*

*Ferro-cement constructions have usually featured an incredible day of frantic effort to achieve a monolithic shell. A ferro-cement ship for the Navy has already been achieved using separate days of successive pouring with the aid of an epoxy provided by Adhesive Engineering Co. (1411 Industrial Road, San Carlos, Calif. 94070). A monolithic structure was obtained by applying an epoxy between the cured section and the next pouring. They also have made monolithic structures of precast cement sections, and stained glass sections.. ....*

*Alan Kalker*

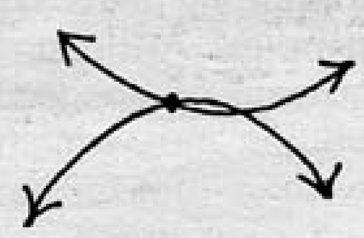


hyperbolic paraboloid

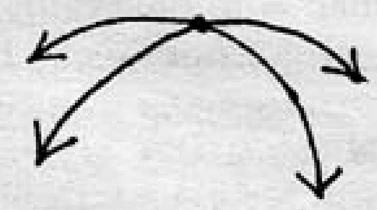


hyperboloid of revolution

Many recent ferrocement thin-shells have been hyperbolic paraboloids, hyperboloids of revolution, and other "saddle-shaped" surfaces. They are double-curved, with the curves *opposed* in direction:



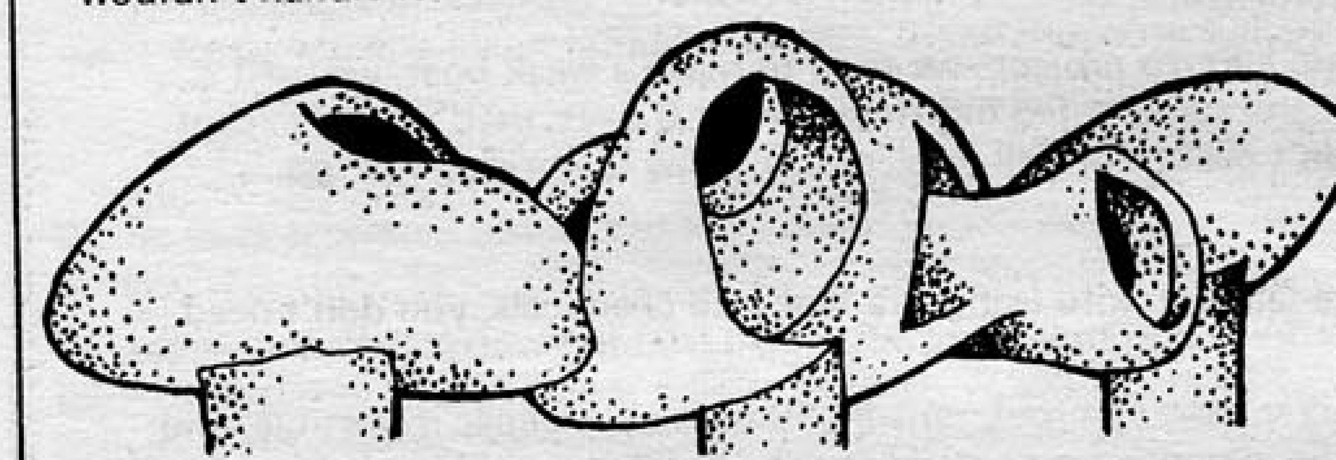
whereas spheres are double-curved in the *same* direction,



The advantage of hyperbolic surfaces is that they can be generated by straight lines, allowing their formwork to be constructed with ordinary wood boards.

However, it should be possible to build small double-curved enclosures without any formwork at all, using the steel armature itself for supporting the wet cement, rather than mocking up the whole structure in wood, then throwing it away after the cement sets. Domes would seem to be ideal, since the spherical skin curves back upon itself, distributing membrane stresses equally, like an eggshell. Since a sphere encloses maximum interior volume per exterior surface area, it is spatially optimum, and the other virtures of domes don't need to be recapitulated here.

Nonetheless just as ferrocement isn't the only way to do a dome, likewise domes aren't the only forms appropriate to the plasticity of ferrocement. Besides the complex-but-regular geometries of hyperbolic paraboloids, you might be able to design and execute a complexly-but-ireegularly curved surface, what swimming pool salesmen call "free-form", but in three dimensions. Structurally you're on your own—even a computer wouldn't handle it—but if that's what you want, this could be the material to use.



Frederick Kiesler's "Endless House"

Advantages of ferrocement domes:

*fireproof*—concrete doesn't burn; the steel reinforcing is insulated thereby and doesn't lose strength even with a fire inside the dome.

*waterproof*—no seams or joints to seal. Ferrocement boats don't leak; all wooden ones do.

*easy enough to build*—Backyard technology suffices; more funk allowable than wood or metal assemblies.

*cheap*—figure it out yourself.

*ecologically responsible*—no organic materials used, and the mineral resources required are very plentiful. With proper quality control you can even dig your own sand and pump your own water (must be potable though).

*permanent*—ferrocement is durable, needs no painting or weatherproofing care, and is quite bulletproof.

Disadvantages:

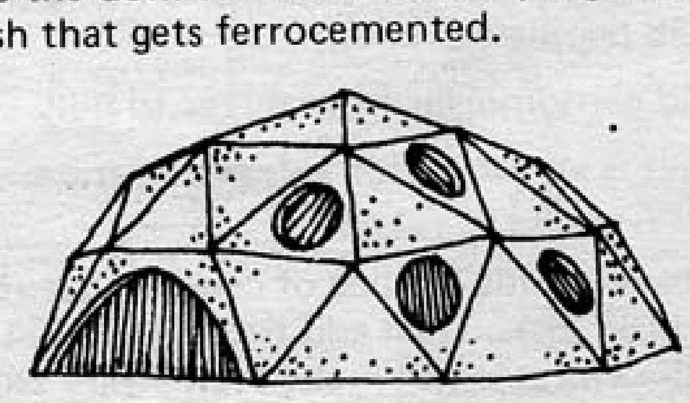
*time*—takes a lot of it. Doing up the mesh especially means days and days of laboriously tedious hand-work, with wire lacerating the fingers. Cementing must then be undertaken in a frantic rush; a boatbuilder estimates 20 hours straight for 25 people working on a 600 sq ft hull surface.

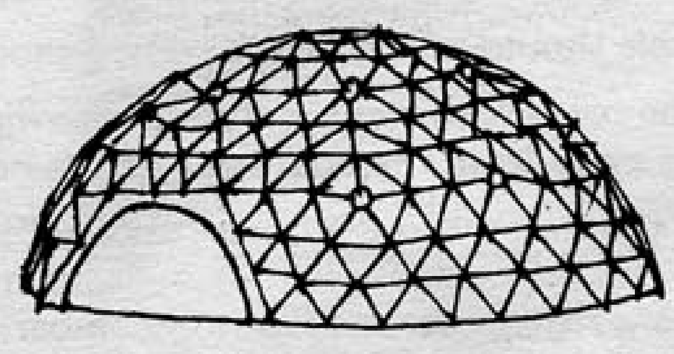
*permanence* again—indestructability isn't always desirable. Ferrocement domes are not mobile, cannot be dismantled and re-erected like wood or metal ones.

## DESIGNING THE FERRO ARMATURE

### A. Geodesic Frames

From the foregoing we see that a ferrocement dome can be structured as a self-supporting spherical shell, without formwork. However perhaps the simplest and safest way to describe the domical enclosure is by a geodesic net of wood or metal struts which support the mesh that gets ferrocemented.





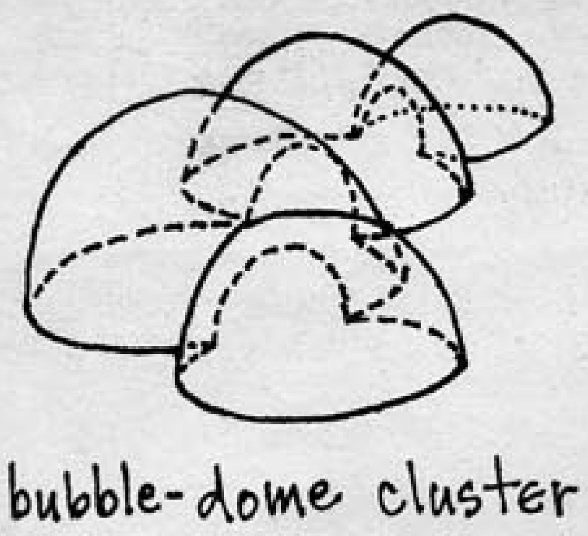
Regardless of the size of the dome, a higher frequency geodesic net will result in a more nearly "spherical" shell, and a lower frequency will give a more "faceted" polyhedron. Although little experimental experience is available, it doesn't seem to matter critically to the ferrocement how spherical it is.

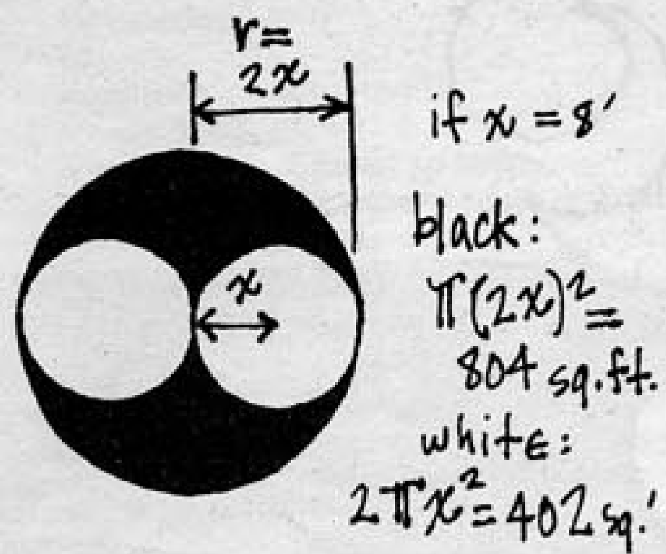
If the mesh is abundant and continuous, and if the application technique is sound, then the ferrocement skin will transfer stresses across the dihedral angles of the triangular planes without cracking. (The skin may tend to sag between the struts when loaded with wet cement, giving a tentlike effect.) Therefore, it might be just as good and a lot more convenient to use a low frequency frame of fewer and larger struts, as did the Jensens.

Since the heaviest load the dome will ever be subjected to is its own wet cement, it really needs a bracing system (independent of its structural shell) only at this time. The geodesic frame, structurally redundant after the cement sets, may then be removed, to be used as formwork for other domes or recycled. Design the hubs or vertex joints to allow undoing from inside, and oil the struts so cement won't stick. Metal frames, such as conduit, are easiest; wood frames might as well be left in if you're going to want something to attach insulation to.

**B. Spherical ferrocement domes**

Accepting as given their structural feasibility, we might first examine some design implications of truly spherical shells. These are new compared to geodesic domes, which are polygonal in plan and section and have no real curved lines or surfaces. Conversely spherical shells have no straight lines or even single-curved surfaces.




On the other hand, you may welcome the freedom from the insistent triangulation of geodesics, especially in the shape and placement of openings. The interior space becomes a seamless womblike hollow and will appear much bigger than it is.

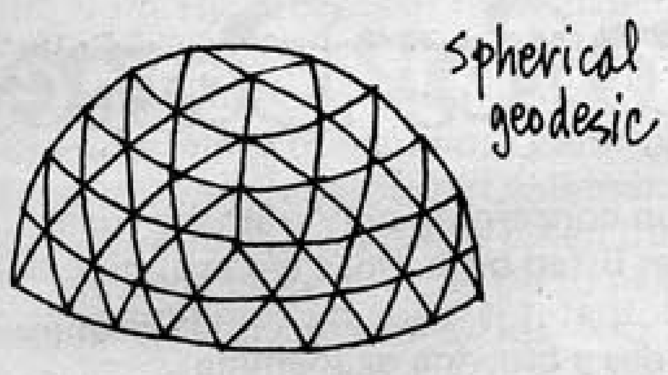
Furthermore it may be lots easier to connect spherical domes to each other without worrying about geodesic geometry, thus permitting clusters of various-sized volumes. You might look at Frei Otto's studies of the way soap bubbles join according to very elegant natural laws. However, note that clusters use more surface to enclose the same floor area(and volume): two domes of x radius give only half as much floor area as one dome of 2x radius. Still you may prefer several separate volumes to one big awkwardly subdivided interior.

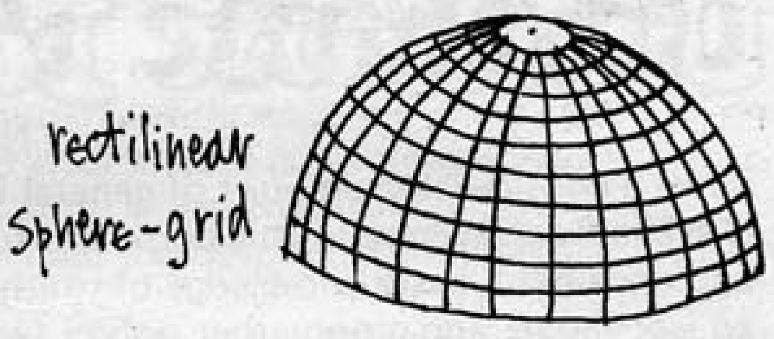
The section-size of the steel members supporting the spherical shell depends somewhat upon the size of the dome, but it's hard to set limits. For the primary framework ½" stock reinforcing-bar works; it's just springy enough to bend under its own weight without kinking, and heavy enough to retain the curve when restrained at the ends. The secondary stringers which mediate between rebars and mesh, may be ¼" wire rods spaced no more than 6" apart, and the layers of mesh go on both sides, symmetrically.

Several alternative geometries suggest themselves for bending the primary bars into a spherical net:

**A. Geodesic** again: with a little spherical trigonometry a geodesic breakdown describes the surface of a sphere rather than a polyhedron. The curved bars would all be great circles, though not all the same length, and such a pattern of reinforcing, built into the ferrocement shell, promises all the geodesic virtues. Experimentation with wire models will determine what frequencies and breakdowns give maximum stability for the dome's size.

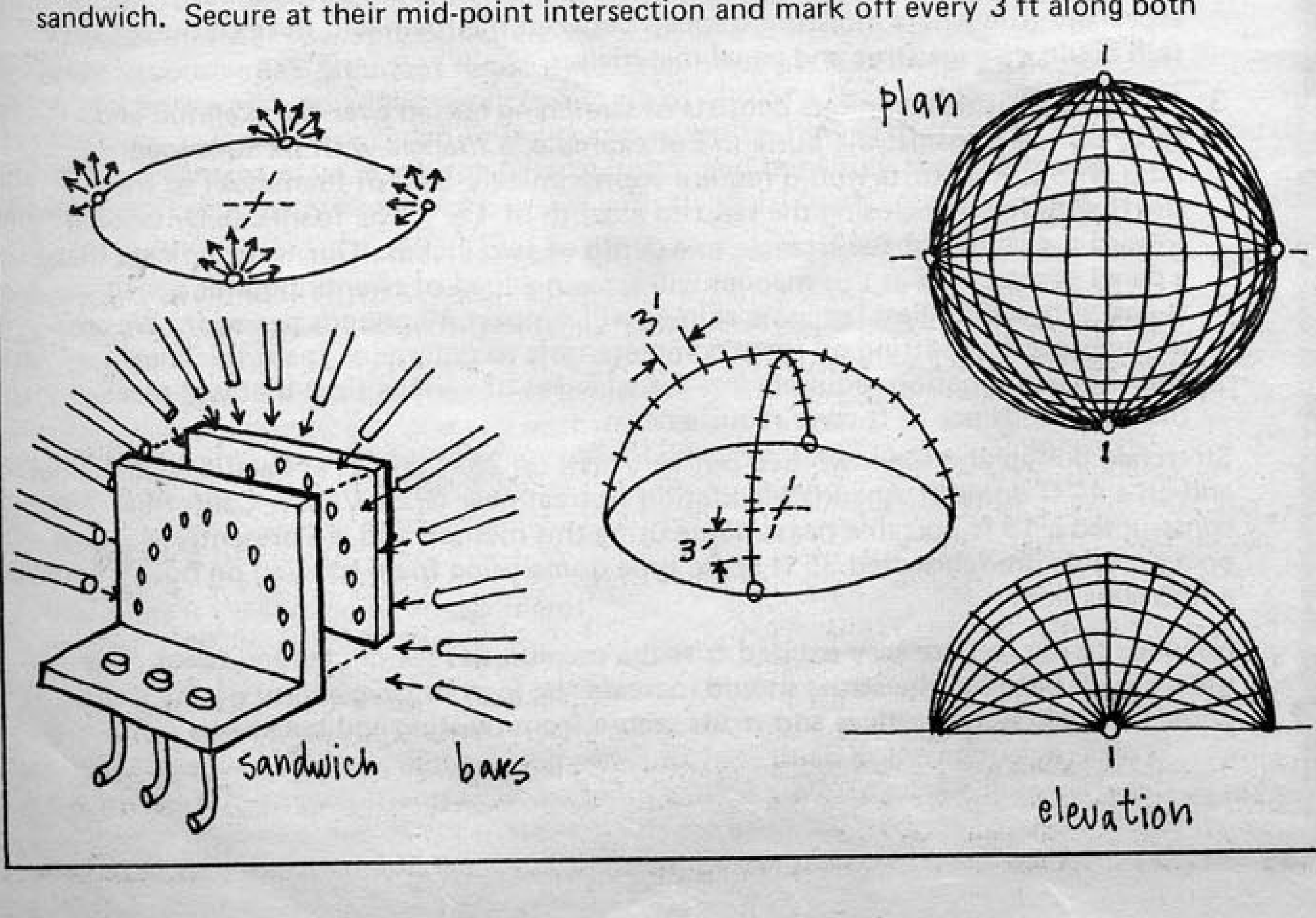
Actually, the world's first ferrocement dome may also have been the first geodesic dome. In *20th Century Engineering,* published by the Museum of Modern Art, is a photo of the Zeiss Planetarium at Jena, Germany, under construction, first noticed by Steve Baer. Shown is what looks like a high frequency triangulated great-circle net of iron reinforcing on which mesh was applied and sprayed with 13/16" of concrete (six German workmen are seen sitting on top of the unsupported dome frame, with no scaffolding, braces, or formwork). The diameter was given as 52½ ft, and the date—1922!



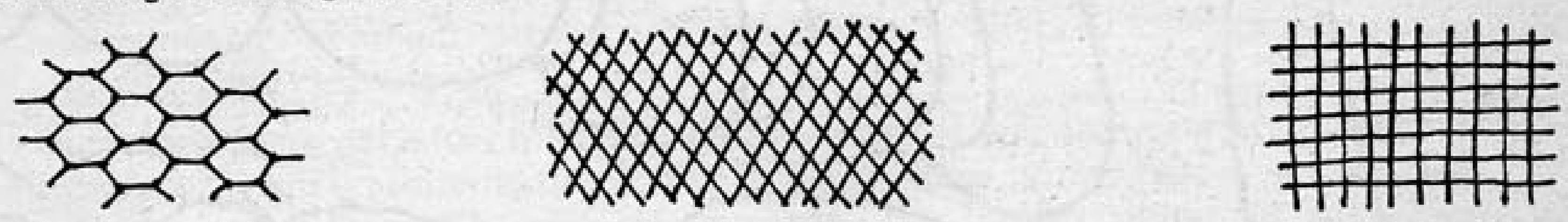

**B. Rectilinear Sphere-grid:** This is easiest to visualize since everyone is familiar with the subdivision of globes of the Earth into longitude and latitude. All the bars meet at right angles so it's not triangulated and thus structurally not optimum. Only the longitudinal bars are great circles; start with those. If stock 20 ft long reinforcing bars each go from the perimeter (equator) to the zenith of the dome (north pole), the circumference = 80 ft and the diameter slightly less than 25 ft. However it is advisable to design a hub for the top, to hold the upper ends of the converging bars; if each bar makes a half-circumference they will be too thick crossing over the pole. The lower ends of the bars may be cast into the floor slab before bending in to the top. The lesser circles, or latitudinal bars, may be of lighter stock or eliminated in favor of the secondary ¼" wire, spiraled down from the top at 6" intervals continuously.

**C. M.I.T. System:** devised by somebody at M.I.T. Since I have worked on a dome using this, it will be described more fully. It's non-geodesic but all bars are great circles. Take the 20 ft long reinforcing bars (75 required) and weld 2½ bars into 50 ft lengths. Thus the circumference = 100 ft and the dome's diameter = 31.4 ft. In the perimeter foundation set anchor bolts at 4 equidistant points. Cast the foundation. Over the bolts will go 4 angle plates, drilled as shown; another plate with matching holes will be sandwiched against the angle to hold the 30 50' long bars. Each of the 4 sandwich assemblies receives 15 bar-ends. Start with 2 bars, one end of each into an opposite sandwich. Secure at their mid-point intersection and mark off every 3 ft along both lengths. The other bars with intersect at these points. Secure their ends vise-like in the angle-plate sandwiches until everything is in the right position, then weld to the two original meridian bars and to the sandwiches. All other intersections may then be welded.




For the secondary rods we used sections of 6" X 6" X ¼" reinforcing grid, the kind used for sidewalk slabs, and it was a fudge-job shaping it, but any other method would work.

We rented a carbon-arc welding rig, which comes with its own generator, and is superior to gas welders which need heavy tanks of oxygen and helium. The spot-welding takes a long time, yet the result is a stable steel net integral with the shell and transfering loads to the ground at 4 points. Variations on this system are possible; try it with 3 or 5 base points to get a triangulated pattern.



**MESH**

The mesh acts as miniaturized ferro reinforcing, a sort of steel fibre in the cement. Various meshes can be used—16 ga. "hardware cloth" with ¼" square grid is excellent but very expensive, and expanded metal, used as plaster lath, likewise. On principle the smaller the holes the better, to save time and reduce thickness of layers. Chicken wire, is commonest in ferrocement practice. However note that when the boatbuilding book specifies ½" 19 ga. galvanized diamond mesh or ¾" 22 ga. chicken wire, this may not be available closer than New Zealand. Most chicken wire in this country is one inch hexagonal pattern.

You therefore apply at least 8 layers, 4 on each side of the primary bars and secondary stringers, overlapping the edges and staggering layers.

It should look like chain mail. If you can stick your little finger through anyplace it's too open. The whole ferro sandwich must be bound together very tightly into a dense mat or else the cement won't stick or will have voids, or the shell will be too thick, or the mesh will pop out and eventually rust through; in any case after cementing it'll be too late to fix and cause great sorrow. *We feel you may be able to get by with less than 8 layers; experiment: make test panels, hit them with a hammer, etc. Boat hulls are framed with pipe or rebar spaced 2'-3'; then 1/8" or 1/4" spacer wire is wired to the frame at about 3" intervals.* Take special care to secure the edges of mesh. Hairpin-like twists of wire, pushed through all layers, will tie them together, but this takes much time; a boatbuilder suggests instead lacing with wire as the last step—keep your stitches tight.

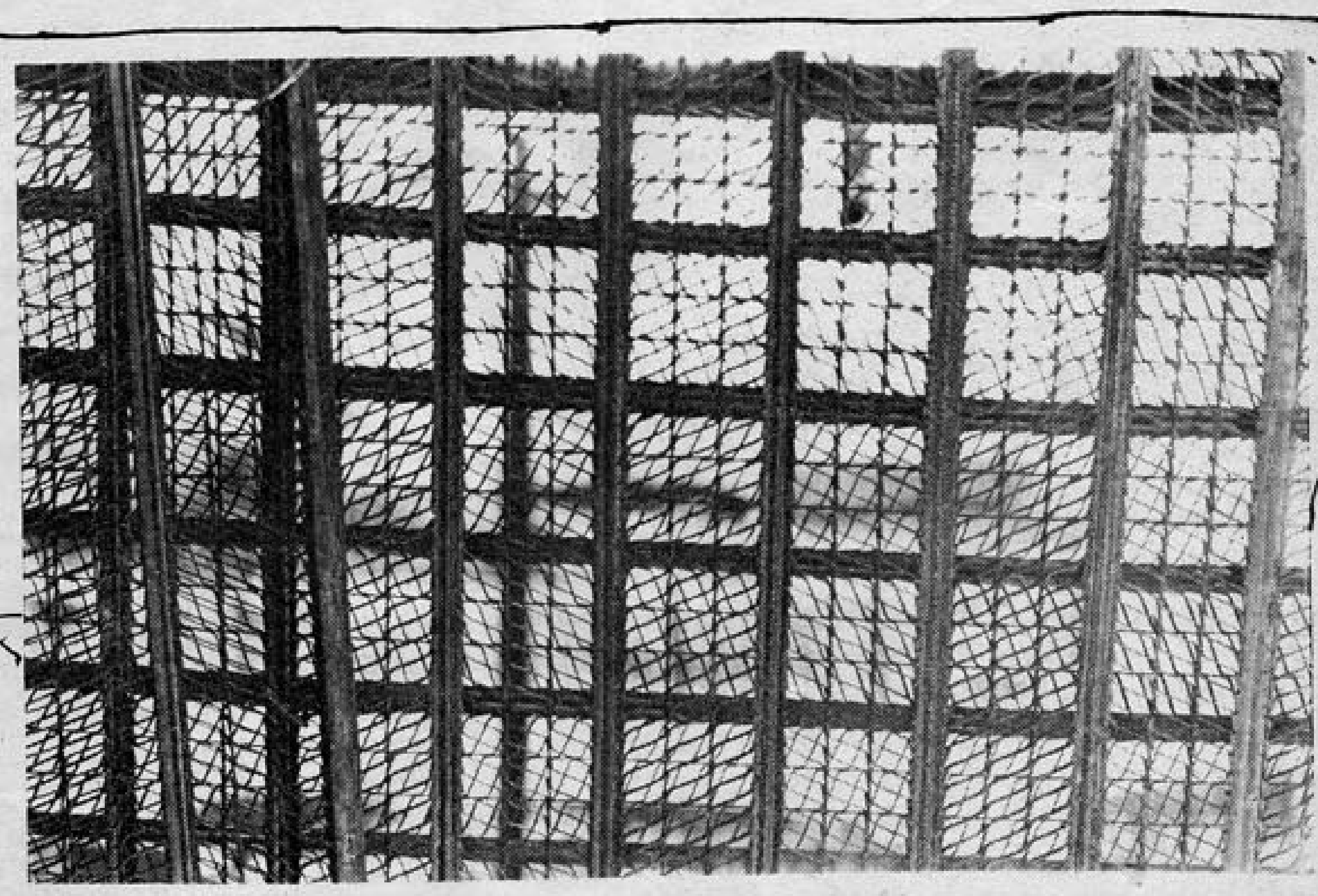
Chicken wire and other meshes come in rolls, which being single-curved, don't fit nicely onto your double-curved surface. You may want to use rather narrow rolls and bandage up the dome. For faceted geodesics take tucks and darts in each layer to form it over the angles. Or prefabricate layers into curvable sandwiches shaped to accomodate the spherical surface or to correspond to flat frame-panels. One advantage of using a wood geodesic frame is that you can simply staple on successive layers of mesh, rather than laboriously wire-tying them to bars or conduit. Anyway, it's important to avoid floppy mesh.

**INSULATION**

If you have a spherical or frameless shell, insulation may have to be sprayed on (sometimes the surface must be specially prepared or coated to make it stick). Even an inch of urethane foam might be enough. If you've left a layer of wire sticking through inside, or have scraped down to the inner mesh, you can try trowelling on a mixture of granular fill insulation (like polystyrene beads) and plaster—this method untested. If you have a wood geodesic frame, especially with large panels, part of the panel structure might be parallel 2 X 4 or 2 X 2 braces 16" or 24" on center, between which insert rigid insulation like styrofoam or rolled fiberglass batts, which are dimensioned to be stapled between studs. Research the problem of condensation—cement walls sweat—and consider installation of a polyethylene vapor barrier stapled between shell and insulation.

**OPENINGS**

You can always defer decision-making until after curing and then cut holes in the shell with a steel-cutting power-sawblade, but unless you plan to sacrificially seal in your workers while cementing you'll need a sizeable opening in the mesh anyway. Even if a triangulated frame is used, no openings should have angles, as these are stress concentration points subject to cracking. Slightly rounded, however, is as good as circular. For spherical shells, circular is easiest. In placing operable windows, remember that domes have unique air-circulation patterns. Doors are always a problem, but with monolithic ferrocement you can flare out the shell into canopies or airlock entries, or insert a separate element, like a 6 ft diameter section of concrete sewer pipe or corrugated-steel highway culvert...



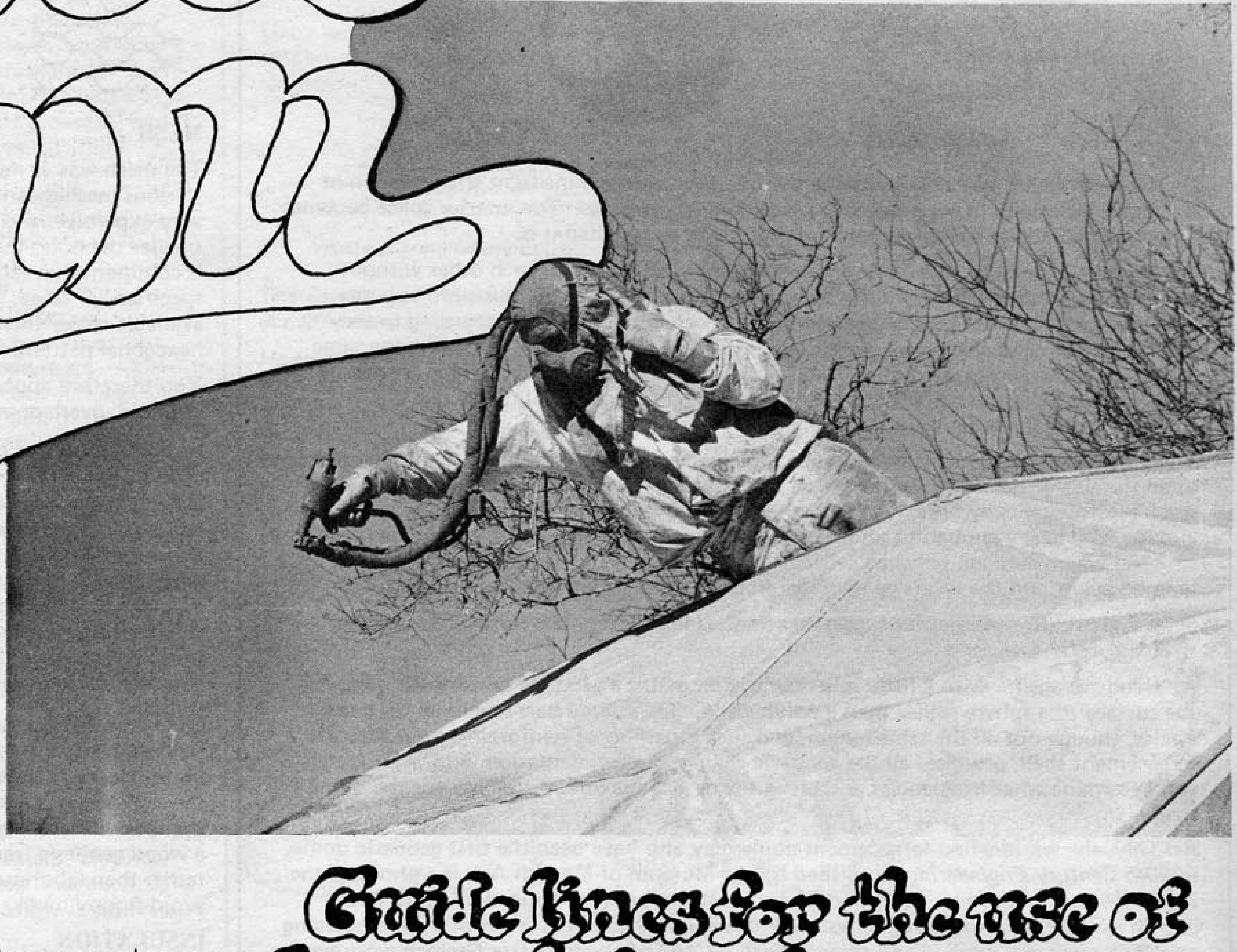
If you are going to try ferro cement construction, two good sources of information:

*Concrete Boatbuilding, Its Technique and Its Future*
by Gainor W. Jackson & W. Morley Sutherland

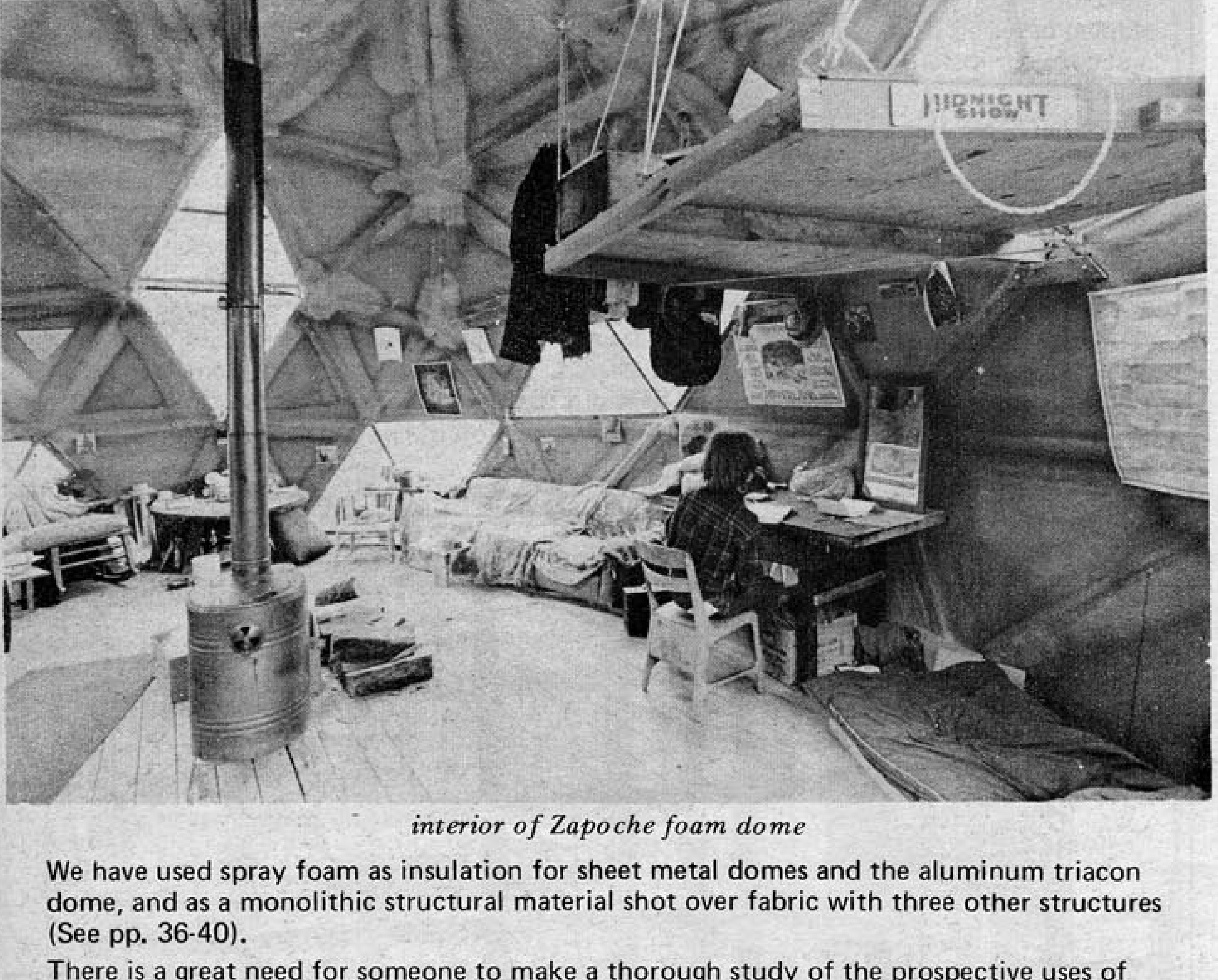
from
John de Graff, Inc.
34 Oak Street
Tuckahoe, N. Y. 10707

Special ferro cement reprint issue, $1, from
National Fisherman
22 Main Street
Camden, Maine 04843

# Plastic Foam



Plastic foams are produced by mixing several ingredients, which produce gases and cause the mass to expand at the same time as it hardens. We have experimented with several types of foam the most promising being polyurethane foam shot from a gun. Besides being the best insulating material known, polyurethane foam could allow the builder to shape his structure on the site. There are, in addition to the liquid foams, rigid board stock foams, which can be combined with other materials such as fiberglass to make structural panels.



*interior of Zapoche foam dome*

We have used spray foam as insulation for sheet metal domes and the aluminum triacon dome, and as a monolithic structural material shot over fabric with three other structures (See pp. 36-40).

There is a great need for someone to make a thorough study of the prospective uses of plastics in housing. We need to know more about the raw materials and the by-products of plastics manufacturing processes. Which plastics are made of soy beans or kelp, and which are made from non-renewable resources like oil? Are plastics actually non-disintegrating?(Polyurethane foam disintegrates 1/16" per year when exposed to sunlight) How much pollution is released into the air as a result of the plastics manufacturing process? I've heard recently that mercury is used in the production of polyvinyl chloride. With a plastic-insulated house, three times as efficient as normal, how much heating fuel do you save and how much less air pollution do you cause over a 20 year period? Can plastics be recycled and reused? I wish we knew the answers.

In the following pages are articles on spray polyurethane foam by a designer, two foam applicators, and a foam supplier. In the insulation section (p. 84) and on the New Materials page (p. 86) is more information on spray foam and rigid foam.

## Guide lines for the use of Sprayed-in-place Urethane Foam for Domes

John Nolan

Since a considerable amount of general information concerning polyurethane foam is available elsewhere in this book and from sources listed on p. 98, I am assuming that my audience has a basic knowledge of urethane foam: that it is made by combining an isocyanate and a polyether polyol (which includes a blowing or foaming agent); that urethane foam has a very fast reaction rate, excellent adhesion and insulation qualities, a very good strength to weight ratio, resulting in many interesting structural possibilities, and though little is known about them, prominent acoustical properties.

### foam on Domes

During 1970 we foamed several domes which were built by people connected with Pacific High School and their friends. Urethane foam is highly adaptable for use with domes as an interior acoustical and insulation liner or as all or part of an exterior skin (These possibilities will be explored later).

The following listing of dome types sprayed and some advantages achieved will reflect our experience to date:

1. Galvanized metal and aluminum skins: foam acts as a sound dampener and keeps metal sheets from booming in high winds or from heat bulging.
2. Plywood skin: foam creates a cave-like rounded edge effect by covering the struts as well as the plywood panels. Covering the struts and hubs seals the dome against leaks, although it should not be used as a substitute for a good tight exterior skin. This rule would hold for all types of skins but is especially true where moisture trapped between the foam and the exterior skin could damage strut and panel materials.
3. Burlap skin: this technique consists of stretching burlap over the skeleton and spraying foam against the burlap. For example, a triangle with six foot long sides with 2 X 4 struts would require approximately 3½" of foam next to the struts with foam enclosing the strut to a depth of 4½". The foam can be tapered toward the center of the triangle to a depth of two inches. Our tests indicate that a panel constructed in this manner will sustain a load of twenty pounds per sq ft and with a fiberglass laminate skin, it will support 40 pounds per sq ft. We are in the process of setting up more complete tests to determine foam thickness and skin combination requirements for triangles of various sizes that will meet the 20 pounds per sq ft code requirements.

Stretched burlap and foam worked out very well on 26 ft domes at Pacific High School and on a 44 ft dome at Ananda Meditation Retreat near Grass Valley, California. We constructed a 13 ft portable pease dome using this method and are presently working on a portable pre-fabricated 35 ft pease type dome using foam sprayed on burlap with a fiberglass skin.

Needless to say, we are very excited over the possibilities for domes and foam. The use of foam between the struts should increase the load bearing ability of any given dome by holding the vertices and struts secure from twisting and buckling.

Any standard foam which is exposed to the sun must be topcoated. Here are several suggestions on how foam can be topcoated. This information would generally apply to coating plywood or other materials, although foam does present some accelerated weathering problems.

## table

| Type of Material | Material Cost ¢/sq ft | Labor Cost ¢/sq ft | Life of System Years | Amount of Strength Added to Panel | Resistance to Puncture | Comments |
|---|---|---|---|---|---|---|
| Acrylic Latex | 5¢ | 4¢ | 3 | None | Very poor | Easiest to apply. Especially poor in high sun load areas. |
| Asphalt type Materials | 3-8 | 3-6 | 2-5 | Slight | Poor | Messy—hard to apply—poor in high sun load areas. |
| Butyl Rubber | 16 | 6 | 8-10 | Slight | Fair | Does good job—fairly simple to apply—good resistance to sun load. |
| Silicone | 25-30 | 6 | 12-15 | Slight | Fair | Does good job—2 component but not too hard to apply—Exc. resistance to sun & weathering. |
| Clear Polyester Resin over Burlap Finish Coat | 10-15 | 10-15 | 5-10 | 50% Increase (initial) | Very Good (initial) | Resin is brittle and has a tendency to crack and check—resin has poor weathering qualities so requires a thin topcoat(gel coat). |
| Polyester Resin Fiberglass Laminate & Finish Coat | 25-30 | 30-50 | Life of Bldg. Finish Coat 5 | 100% Increase | Exclnt | Best all around—does require renewing finish coat. |
| High Density Urethane Foam—Experimental | 15 | 15 Contractor Only | 5-7 | No test available est. 40-50 % (initial) | Good | May be available in late 1971. Self-weathering or can be painted, which would extend the life of urethane skin. Should be an excellent solution to problem. |
| Elastron No. 850 | 15-20 | 6 | 10 | Slight | Fair | One of the best long-lasting flexible coatings for urethane foam |

## foam facts

Unfortunately for the do-it-yourselfer spraying urethane foam that *looks good* requires an experienced sprayman using good equipment. This is not to discourage anyone who might want to learn to spray foam, because there is a big demand for spray foam mechanics. Just don't try to learn how on a dome. Dome work is as exacting and tiring as any foaming I've done.

What then do you need to know in order to secure a proper foam job at a proper and reasonable cost? The 2 chemical components of urethane are quoted on a cost per lb basis. Standard foam, having a density of 2½ to 3 lbs per cu ft and a flame spread rate of 35, costs 48 cents per lb or $1.44 per cu ft. Fire retardant foam with a flame spread rate of 25 and 2½ to 3 lb density costs 70 cents per lb or $2.10 per cu ft. Spray applied urethane foam is usually quoted to a customer at so much per board ft (1 sq ft 1" thick). One cu ft at $2.10 yields 12 board ft, so the material cost for fire retardant foam is 18 cents per board ft. Commercial application rates will run from 15-30 cents or more depending on many factors such as size and location of job, etc. Be sure to find a contractor who is interested in this type of work as many are not. If you want to save money, plan on doing as much work as you can yourself as preparation, masking and cleanup, provide staging if practical, anything you can think of that will make the contractor's work go more quickly, and then be sure that all this is taken into consideration when establishing the price. Also, the more you can do to help the sprayman the better job you will get, because he can concentrate on his work.

In the previous paragraph I compared 2 foams. The only major difference in the 2 was the flame spread rate. A testing procedure, ASTM-96-E, has been designed to determine the flame spread rating of various materials. The test determines whether or not the test material contributes fuel to a fire. A 25 or below rating means that while the test material is consumed, it does not add fuel to the fire. This is a fire retardant foam. Another term used in discussing the burning characteristics of foam is "self extinguishing". This means that if the heat source is removed the fire will go out. However, even though standard foam has a flame spread rate of 35 and is "self extinguishing" it should not be left exposed in a foam enclosed structure such as a dome. The low density and high insulating efficiency of foam create a situation in which a relatively small fire (waste basket) could superheat the air and a large surface area of foam to its autoignition point (800°) at which it bursts into flame. The foam goes through destructive distillation thus creating a large amount of highly flammable byproducts, and a flash fire situation may result. Foams with a flame spread rate of 25 or less resist the distillation effects and a self protecting charr forms on the foam surface. If your design plans call for more than an 1¼" of foam, you could use standard foam for the major buildup and achieve the same fire retardancy and a savings by using a final ½" of fire retardant foam.

An alternate fire retardant system would involve using standard foam and an intumescent paint coating over the foam. This will give good protection against the flash fire and will cost approximately the same as a system using one inch of the more expensive fire retardant foam. Intumescent paints cost $6 to $7 per gallon and have a recommended application rate of 100 to 125 sq ft per gallon. Its effectiveness is directly related to the thickness of the film so don't cut corners. Use of fire retardant foam is still the best approach and hopefully the cost of the chemicals will soon be brought more in line with standard foam.

Another development which may be ready for commercial use in 1971 is a sprayable high density foam (22 lbs per cu ft). This material will be sprayed with the same equipment as the standard foam requiring only the use of a different resin component. 1/8" of this foam over standard 2½ to 3 lb foam or over the burlap as mentioned earlier will serve as an exterior monolithic skin which will give good resistance to physical wear, punctures, etc. and will withstand direct exposure to sunlight. It can be painted after a weathering period. The cost for this will be around 30 cents per sq ft applied.

## hints

General hints if you are going to use foam:

—regarding foaming technique: The manner in which the foam is handled around the struts affects the finish appearance a great deal. If your system design calls for the use of foam as a structural component the foam should be built up to the full thickness of the panel near the struts and tapered down to 1-2" thick in the center to create a flat arch inside of each triangle. Some foam will be built up on the interior face of the strut giving a visual effect that the struts are enclosed, rounded and the sharp angles give way to curves and seem to flow into the natural curves and arcs of the dome. If you want to use foam for its insulating and acoustic value, i.e. in a dome with a plywood skin, you could still completely enclose the struts as described before or build the foam up along the sides of the struts but not cover the interior face, or apply the foam evenly over the plywood and not let it build up along the struts. Enclosing the struts obviously requires more time and material than spraying a flat surface. If you want a minimum of 1" of foam but want the struts enclosed this would average out to approximately the same as 1½" of foam on a smooth surface. Leaving the struts exposed requires masking or scraping to remove overspray and will not protect against leaks as well.

—cutting and sanding foam alters the appearance and tends to give a patch appearance.

—an ounce of masking to protect against unwanted overspray is worth a pound of scraping and cleaning up.

—urethane foam has a low tolerance for moisture. If you are using wood, and it is moist or green you should prime it with a water base primer before putting it up. This paint can be applied in a very thin coat. This is especially important during cool or damp weather.

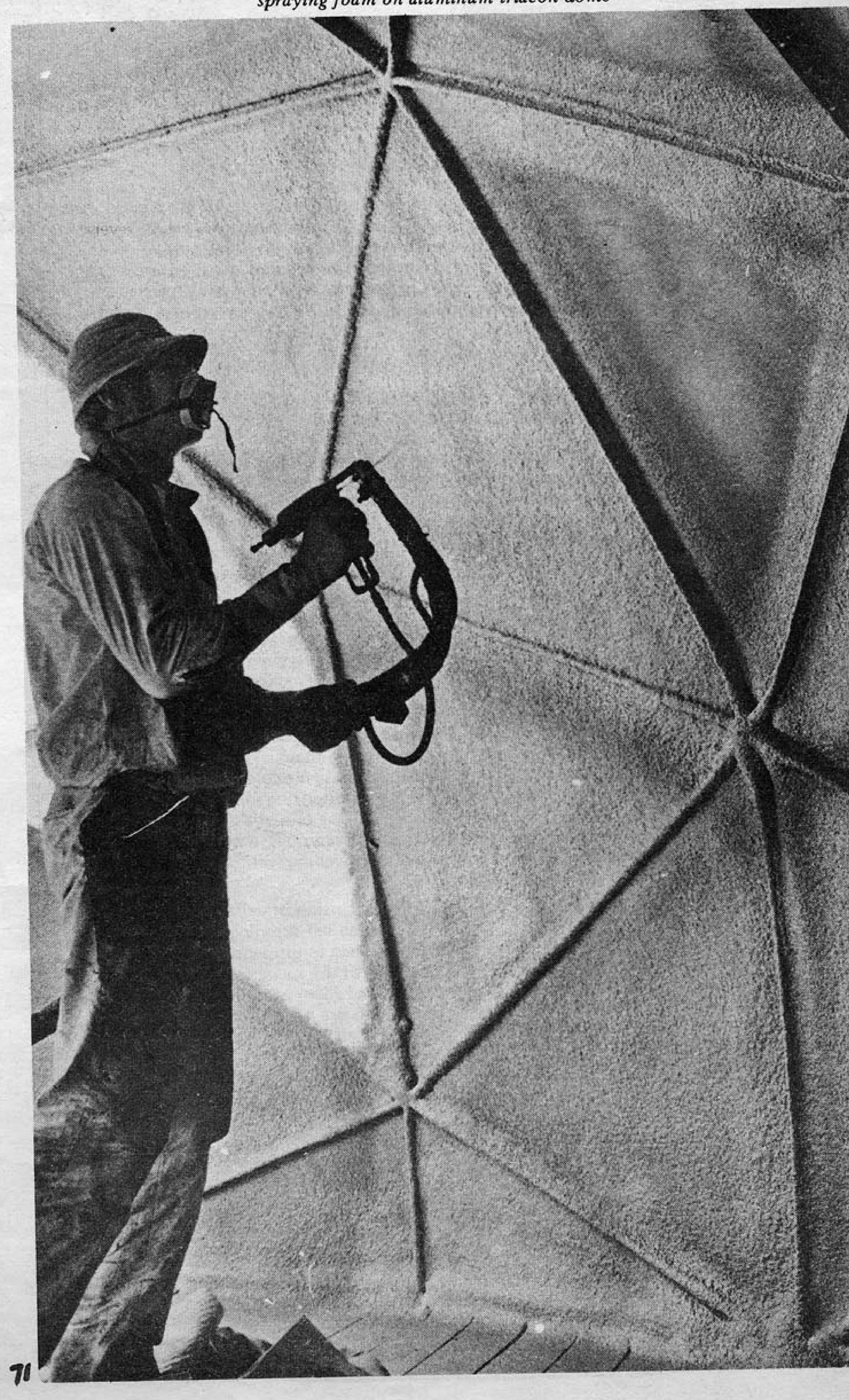
—foam will bond to most other building materials. High gloss aluminum and stainless steel or oily galvanized metal may present some problems, but these could be easily overcome by priming with a vinyl wash coat type primer. Some plastics are smooth and resist chemical bonding. Something as simple as acrylic latex may work as a primer in these instances. Manufacturers of the various plastics can usually recommend a primer or adhesive. If you are going to use an exotic material, try to set up an adhesion test.

—We have sprayed foam against plastic window screen. It allows too much foam to pass on through to be classified as a good backstop.

—foam is moderately effective in dampening sound waves which pass through it. It is roughly ½ as effective as acoustical fiber board in this respect. Foam is rigid and has a tight, hard although textured surface. As such it has a relatively low absorption potential for sound emitted inside a structure. As a result sounds in a foam dome have a "live" quality. For some uses and in larger domes(above 40 ft) this "live" quality may be excessive. I expect to have more information on foam domes and sound ready for *Domebook Three.*

*John Nolan is the owner of Central Coating Company, 205 South I St., Madera, California 93637 and specializes in urethane foam and associated coating applications such as wine tank insulation, cold room insulation and structural uses of urethane foam and plastics in general.*

*spraying foam on aluminum triacon dome*



# Foamed Plastic for Shelters

Douglas Deeds

One of the most important aspects of foam technology is the totally organic nature of the material. This would also apply to some of the reinforced plastic materials as well. For the first time in the history of mass produced materials we have components capable of being made into any conceivable shape and form. The use of the material has not been limited to some pre-formed industry-issue shape such as an "I" beam or four by eight sheet. No longer are we given limits based on what is convenient for the machine that makes the materials with which we build.

This, of course, leads to an aesthetic dilemma. We have developed a taste and fashion sense around the straight line. Suddenly, all stops have been removed. This is sort of scary for those trained in the dogma of triangle and straight edge. It is also uncomfortable for consumers who have been raised on the gruel of equating straight lines with man's dominance over materials and nature. Now we have materials that, at least in form and configuration, can be in harmony with nature.

What advantages does foam offer in the construction of a shelter?

The use of foamed plastics for shelters, as stated above, completely frees the form and shape of the end product. This is much more important in its ramifications than simply allowing the constructor free reign in exploring his whims. The structure can be completely site-adjustable; it does not require the leveling of the terrain to make it convenient for someone to pour a concrete slab. The structure can be in complete harmony with the site—not an eyesore on the landscape or, worse, a cause for scarring the landscape.

Foams and other reinforcing materials (such as fiberglass reinforced plastic) allow total fabrication of the shelter on the job site. The key concept here is that the factory is, in essence, brought to the job in the form of a small mobile unit capable of applying foam and reinforced plastic. The molecules jumping around in the barrels still haven't been told what shape to be. Also, they are not in pre-shaped sheets, tubes, etc., which are bulky to transport. Foamed plastic expands to many times its liquid bulk upon application, providing economy of material. Two gallons of material thrown together suddenly expand to become several cubic feet of rigid material. The equipment needed to erect the basic shell of such a structure can easily be contained in the back of a small truck. Because there are only, at most, two or three materials used (all transported in drums or condensed state) there isn't the bulk transportation problem encountered with conventional building methods.

Mistakes are mendable with the use of foam. The error can be carved away and new foam "grown" in its place. Small details can also be introduced by carving into the cured foam. As an added benefit, cured foam proves to be a moisture and vermin resistant material...

The creation of the raw materials, from which a synthetic house is created, cause a resource depletion. However, if a synthetic shelter performs more efficiently, and does not generate further resource depletions, it is surely a step in the right direction. Conventional building techniques drain resources from the outset and their sieve-like inefficiency demands further consumption in the form of great quantities of gas and oil to heat and cool them, to say nothing of the excess pollution caused by the inefficient transport of large, bulky materials to the job site. These factors are, obviously, reduced by the low bulk, site-adjustability, insulation quality of foam structures...

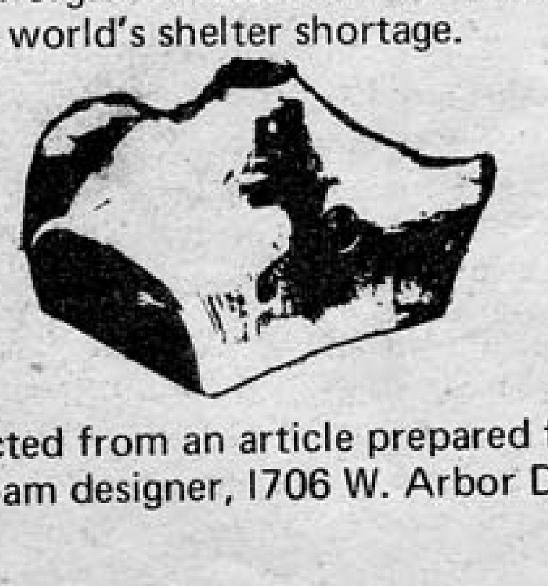
What are some of the construction techniques available for foam shelters?

There have been a number of foam structures erected, during the past couple of years, using the inflated technique. Basically, one simply inflates a large balloon-like form with air and sprays urethane foam over it. The foam rigidifies, the air pressure is removed and a structurally sound building remains. The cutting of window and door apertures creates a "house," and some of these structures have been quite large. However, I find that the inflated structures have been limited in form and just scratched the surface of what might be achieved...

Last September, I was privileged to design and construct an exhibit structure at the Smithsonian Institution in Washington, D.C. For this structure, I used a proprietary technique—stretchable fabric spread over tubular plastic arches. This formed the matrix over which the urethane foam was sprayed. There is great freedom of form possible with this method and it is very easy and inexpensive to construct such a matrix. The fabric surface makes the spray application of foam very simple and minimizes the labor involved ...

At the present time, there are firms in the country who are experimenting with molding large foam building modules, using self-skinning foam. They hope to be able to produce a high volume of low cost housing. These modules may prove feasible for this need. Obviously, the costs of capitalizing such an operation, and the research necessary, put it beyond the reach of the one-of-a-kind, single family dwelling market. However, as urban crowding continues, the one-of-a-kind market will logically dwindle and the mass produced dwelling will find an ever broadening market.

As for the future of foam, it rests mainly with the expansion of existing trends in the materials development. We are sure to see self-skinning foams that will not require the use of exotic molds. Resistance to ultra-violet light degradations will be improved. Greater control of the surface finish will be possible, and certainly, simplified techniques of foam construction, without exotic equipment. It may even be possible to pre-program the molecules of the raw components so that the foam itself will know what shape and variety of densities to form without any outside help. One thing is certain: these new organic materials offer the broadest spectrum of potential for aiding the world's shelter shortage.



The above was extracted from an article prepared for Domebook One by Douglas Deeds, foam designer, 1706 W. Arbor Drive, San Diego, CA. 92103.

Materials Supply Company and Pittsburgh Plate Glass gave us the self-skinning foam used in the Zapoche dome(p.39) gratis for experimentation. Paul Carothers arranged this for us, thru Central Coatings, and wrote the following article on foam, the suppliers' viewpoint.

# a Dissertation on Foam

As you approach the subject of applying 2 lb density urethane spray foam to your structure, you should be aware of the several advantages and disadvantages of the system, as well as its various limitations:

**Spray Equipment:** Portable spray equipment is available from numerous manufacturers. Chief among these are Gusmer Corp., Binks Manufacturing Co., Graco Corp., DeVilbiss Corp. All equipment with its various supportive accessories(air compressors, generators, pressure-fed supply tanks, etc) is expensive—$8000.00 to $15,000.00—so we advocate hiring a qualified foam applicator.

**Qualifying the Applicator:** Get someone who is experienced and trained; ask for job references and look at his work. Look at work similar to what you require(inside and outside). Look, if possible, at work in progress under weather conditions similar to what he'll experience on your project. Look at the applicator's equipment, judging him by its upkeep and completeness. Make sure he has equipment with an adequate pre-heater and that his material supply lines are heated. Do not hire him on the basis of a cheap price.

**Negotiating With the Applicator:** You can gain the applicator's most favorable price by exhibiting flexibility in job scheduling to take advantage of his slow periods. You may cut your cost by doing your own preparation, finishing, and cleaning up. However, remember the applicator has fixed expenses regardless of the size of the job in travel time, set-up time, machinery maintenance, and machinery depreciation, as well as his fixed overhead. Don't expect foam to be inexpensive. Interior foam applications will run from 1/4 to 1/3 higher than outside work except in inclement weather.

**Surface Preparation:** Surfaces should be dry—dry—dry! They should be clean and sound(no peeling or flaking). Metal should be rustless and oil-less—galvanized metal should should be acid-washed(vinegar is OK), then flushed—then allowed to become bone-dry. Sound primers on all surfaces help, but are not mandatory. On exterior surfaces, black primer(asphaltic cut-back is generally OK) work to your advantage because of heat absorption and even heat distribution. Remember, foam adheres to almost anything(except oils, waxes, silicones, bond breakers, some plastic films on initial contacts), but that anything must be well stuck to the substrate to insure the product's dimensional stability.

**Application:** Surfaces must be dry! It is to your advantage(especially when you are buying your foam by the unit [or pound] used) to have a warm surface. For standard foams(P.P.G. 6516 SP) it should be from 70°F to 100°F. Generally the warmer the surface the greater the yield of the material used(e.g., thickness per pound per sq ft sprayed). If you spray on cold surfaces(70°F to 32°F) a more reactive foam(P.P.G. 6516 S) or preferably a cold weather foam(P.P.G. 65012) formulated for Freon 12 addition should be used. On surfaces over 100°F, use a warm surface foam(P.P.G. 6516 P).

Since you get the best yield(more for your money) from standard foam, attempt to time your spraying for good warm weather. If not possible, attempt to warm the surfaces(e.g., put a space heater inside the structure when spraying outside to provide warm surfaces even in cold weather).

You cannot spray outside in windy weather without an adequate wind shield.

Long runs of burlap on a frame will do if practical. It's easier to wait for calm (wind under 5 mph).

Protect surrounds from overspray (cars, buildings, your treasures). Clean eyeglasses by soaking in warm soapy or detergent water overnight—wipe hard with a soapy washrag the next morning—you may have to use your fingernails on a few tough spots.

**Health Factors:** One of the components in urethane foam is isocyanate, which joins with moisture to form a solid. Fine particles in the air will form small specks on mucuous membrane, irritating the eyes, and respiratory passages. Many people develop symptoms similar to asthma from slight exposures. Many become permanently allergic to urethane spray and allied materials. Consequently, protect yourself—wear organic air filter masks and glasses during exterior applications; fresh air masks during interior shooting. Cover your flesh as much as possible; use a salve or cream to protect exposed flesh. Do not repeatedly wear foam contaminated clothing.

**Clean-up:** Urethane may be easily shaped with a Stanley serrated blade plane or a sander (the latter throws fine particles all over, so protective glasses and a mask are must-requirements). If you desire to shape foam, do so, but, if possible, have the applicator apply a sealing skin coat over the opened cells. If he is not available, fill the open cells (polyester resin is fine) before finish coating.

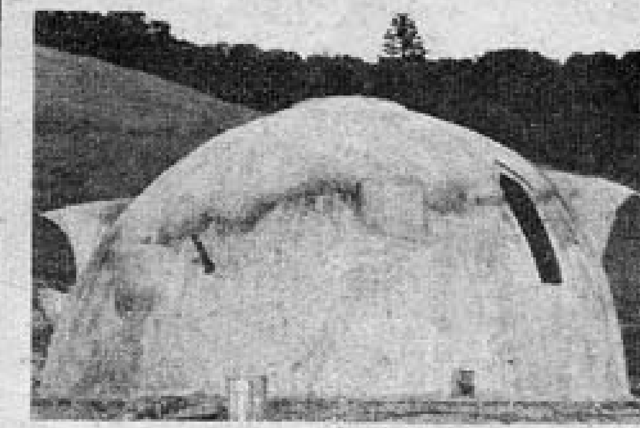
**A Special Note:** If your foam application extends over several days, avoid problems with poor foam melding at overlaps by cutting back a 3" to 4" wide strip along the previous day's edge where the new foam is to join. This cutting down into open celled foam removes the overlying skin which probably is damp from overnight dews and as such would prevent good adhesion from new foam to old.

**Other Urethane Foam Spray Products:** You may have special design considerations which require other spray foams. Standard foams are nominal 2 lb density(2 lb per cu ft), but when applied under adverse(cold) conditions may reach 2½ to 2¾ density. P.P.G.'s cold weather foam(65012) has a very slick, tough skin and normally is about 2½ lb density; it may run to 3 lbs or more under adverse conditions...it should always be sprayed with some Freon 12 content. P.P.G. 65018 is a 4 lb density foam used for coating roofs where foot traffic is likely. A new 22 lb density foam is being researched as a finish coat. P.P.G. 65058 is a new 2½ lb density foam with a UL flame spread rating of less than 25.

**Finish:** Your urethane foam should be finished on the outside with an opaque long-lasting paint to protect it from ultraviolet light degredation. It should be finished on the inside(unless UL25 flame spread foam is used) with an intermissent fire-proof paint.

We wish you the best of luck in your urethane foam structure adventure!

Paul A. Carothers
MATERIAL SUPPLY COMPANY
Sacramento, California 95828



*dry mix*

# FERROSTONE DOME

Peter Calthorpe

With our ferro cement dome at the school we tried to approximate a smooth curved surface by bending a kind of peel frame with ½" rebar radiating like spokes from a central hub to the ground. The frame looked like the longitudinal lines of a globe; we added no horizontal framing as that would have created inch thick intersections. Since we were using expanded metal (which has integral ribs), we felt that ¼" rod was not necessary. Boat hulls are framed with reinforcing steel spaced 2'-3' apart; then 3/8" or 1/4" spacer is wired to the frame at about 3" intervals. It was only a twenty footer and was to be used for toilets and washing machine. When we poured the cement floor it had one foot pieces of rebar sticking up around the perimeter, we wired the longer rebar onto them and wrestled them into a hub at the top. The frame didn't come out spherical at all, but nobody seemed to mind.

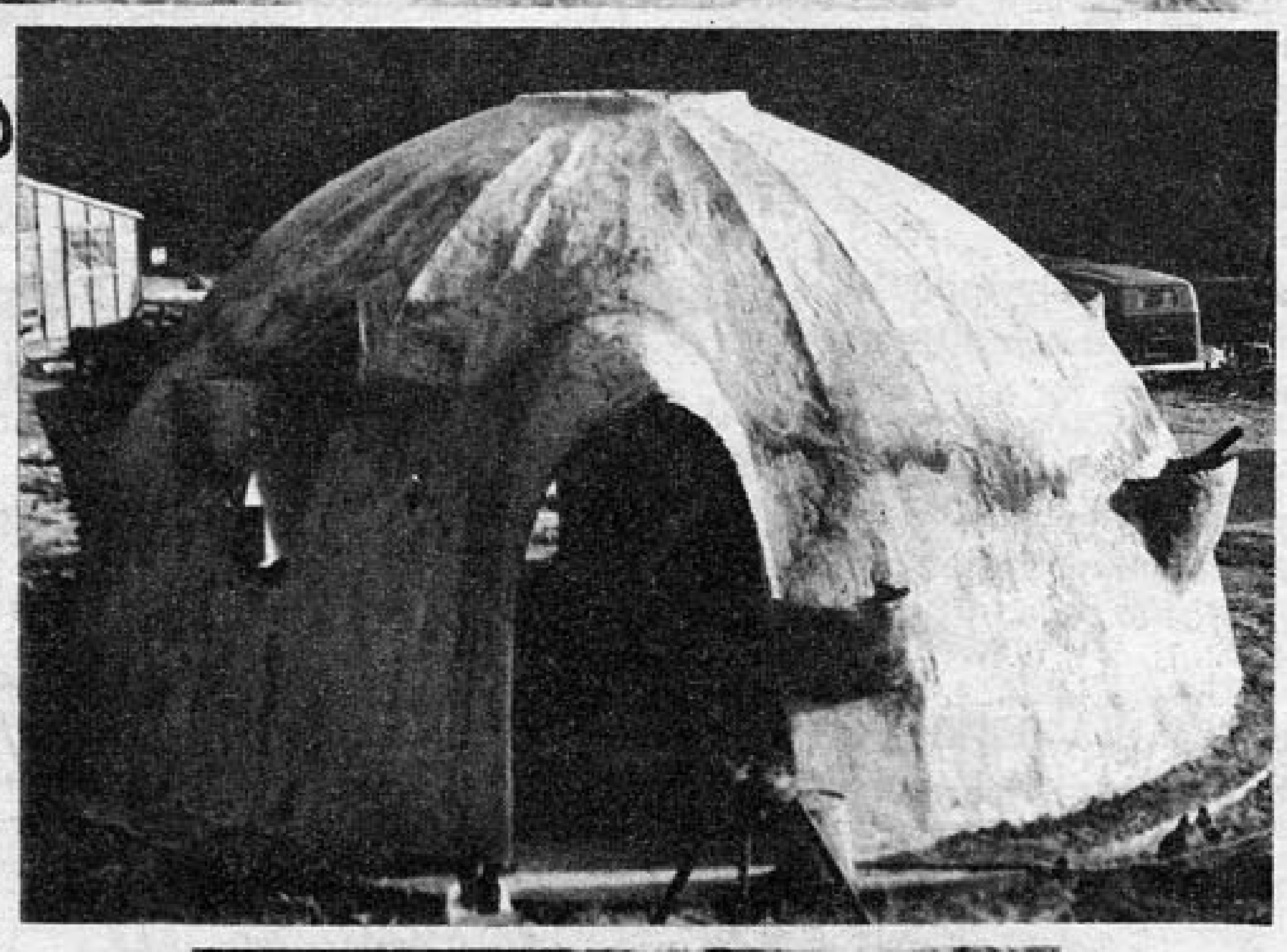
Since then it's turned out to be an extremely tedious job. To begin with, expanded metal is not good at distorting into compound curves; if you decide to make a curving structure by all means use chicken wire, it may take more layers but it will be easier to work with. Further, wiring the layers together is painstaking and has taken many more man hours than we ever expected. It seems that stapling the metal onto a wood frame in planar sections would avoid both of these pitfalls and also provide a reliable superstructure for the tons of wet cement.

As final touches we made some freeform entrances and wired in a few plant boxes on the outside. As we were doing this I realized that we were just touching on the possibilities for freeform details: furniture could flow out from the wall, cabinets, dividers, storage, lofts and fireplaces could all be built in. After finishing the tremendous job of twisting those thousands of wires (a good idea I noticed in a boat building book was to weld a small pair of vise grips onto a drill bit and use a power hand drill to twist the wire) while dramatically hanging from a trick ladder I realized that we had to build a scaffold to accommodate the hordes of plasterers. Best to build your scaffold after completing the frame and use it to work on the mesh as well as the cement. Our scaffold had eight legs strapped to a pipe hub about two feet above the mesh and two by fours ringing it for people to stand on. Better for larger domes would be a low frequency geodesic frame.

The things really necessary for plastering day were: heavy cement gloves for everyone (trowels and floats didn't work well at penetrating), plenty of five gallon buckets to distribute the mix, more than enough sand and cement, a paddle type plaster mixer, around thirty people, and food. You can get old paint cans from paint manufacturers. The gloves are expensive (five dollars a pair) but necessary; get them from cement dealers.

We didn't use a vibrator box or any of the special chemicals which are supposed to make penetration easy. With only two layers of mesh I thought there would be no trouble with penetration; however it ended up being hard work to push the cement through. Plastering from the inside gets hard when you get to the top because the cement falls off into your face, and has to be almost dabbed on. Next time I'll not plaster the inside and simply shoot it with a little foam; the structure needs some kind of insulation anyway.





Each person you talk to will give you a different formula for the mix; we used the simplest, funkiest method mentioned. Used Portland no. 2 cement in a one to two ratio with Olympia no. 1 even graded sand. We got some extra bags to measure the sand in, one bag of cement to two bags of sand; the cement to sand ratio is not that critical, we must have varied at times down to one and a half bags of sand — the critical ratio is water to cement. Even graded sand means that the sand has all different sizes of granules which allow the mix to be denser because the sand can close pack and leave less air spaces. About ten pounds of pozzolan, a kind of powder, per bag of cement is used to make the mix even denser. Three and a half gallons of water seemed like the minimum and we often added more if it felt too dry and crumbley. I tried baking the sand to check out the amount of water it contained, but my scale was too inaccurate; didn't use a sump test either just took a handful, pressed it into the mesh, and if it looked ok we'd use it.

The mixing went like this: water, cement, pozzolan, then sand. Let it mix for about five minutes to get all the water evenly distributed. It will seem too dry at first but after a while you'll get a sense of how it should be. The most important qualities about the mix is that it be dry and dense. If it is too wet, surface cracks will develop when it cures. I was worried about the mix but there was no need, you really can't go wrong. This dome was actually a test in how funky one could be with ferrocement and the conclusion is, very.

I was told that it took about ten pounds of mix per square ft. of surface area, so with a twenty ft. hemisphere which is 600 sq. ft. we figured 2000 lb. (20 bags) cement and 4000 lb. of sand. Also told one would need about one and half times as much mix as was to end up on the structure, so that hyped the order up to 30 bags of cement, which is just what it took. The cost of the mix was about fifty dollars.

The frame didn't sag as I thought it would but it shook at the bottom as we were plastering around the middle of the dome. When all the mesh was wired the dome had such a unity that shaking any part would cause the rest to move. Because of this the cement was sagging and cracking around the base. So we stopped about half way and let it cure for a few days before cementing the rest. Using a wood frame would prevent this shaking from happening.

Curing is a chemical reaction in which the cement and water grow crystals which are the strength of the mix; it is not a drying process like adobe. In fact drying will stunt the growth of those crystals and will result in a weak concrete. There are many methods of curing but the simplest seemed to be to spray the dome with an epoxy sealant called P.C. proco, available in different colors from P.C. Western Chemical in S.F., and trap the moisture in the wall. The sealant also functioned as a bonding agent between the cured cement of the first day of plastering and the fresh cement of the second half.

One thing you need not worry about is the strength of the shell, all the stories are true, if you hit it with a sledge hammer it will bound out of your hand. Its a very hard surface so the acoustics are bad, another reason for foam on the inside. It really does seem like the ultimate low cost building material, its only drawback could be its permanence, which also seems ultimate.

# FLOORS

The floor of a dome should be carefully considered.
We will describe wood, concrete, and some experimental floors.

### WOOD FLOORS

These domes were built in a small valley at about 2,000 ft elevation in the California hills. Our temperature range is from about 30° to 95°. The ground freezes in the winter, but it is seldom cold enough to freeze water in the nearby lake. Summers are hot and dusty. Being in the valley, we don't get strong winds. We get a lot of rain—50-60" per year, and snow maybe once per winter.

Most of the domes are on hillsides, and we have built wood floors for all but the bath and toilet domes. The floors for our first domes were square. This didn't work well, as the dome gets full peripheral support in only four places, with other sections not having enough support. A square floor is OK if there is to be a deck as part of the structure. Jay and Kathleen built the first radial floor, and all the floors we've built since have been radial.

We have used two types of flooring material with the radial floors—plywood and 2" X 6" tongue and groove subfloor lumber; and we have used two different framing shapes: pentagon and hexagon. The first instructions are for a hexagon frame; adjust accordingly for pentagon.

**Note:** *These floors and foundations will probably not pass building codes in most areas. If you're going to get a building permit, ask the local building inspector how to bring these floors up to codes, and see suggestions on opposite page:* For the Building Inspector.

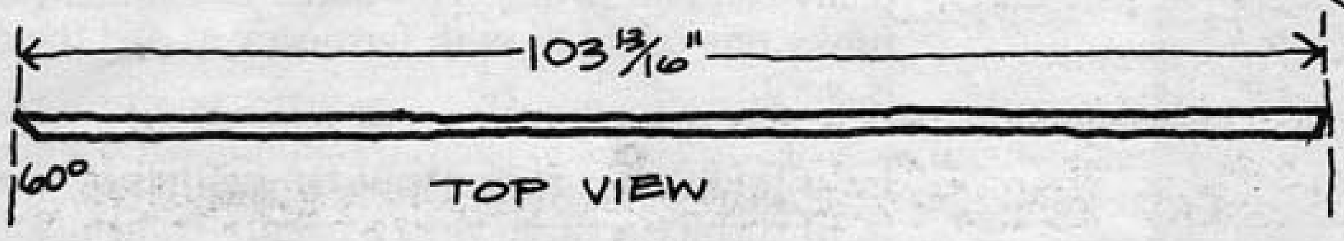
### GENERAL FRAMING INSTRUCTIONS FOR HEXAGON 24' DIAMETER FLOOR

Tools needed: shovels, two 12' tape measures, combination square, 2 plumb bobs, hand level, straight-claw hammer, 8d and 16d nails, pick if ground is hard, saw, small sledge hammer.

Lumber list for frame:

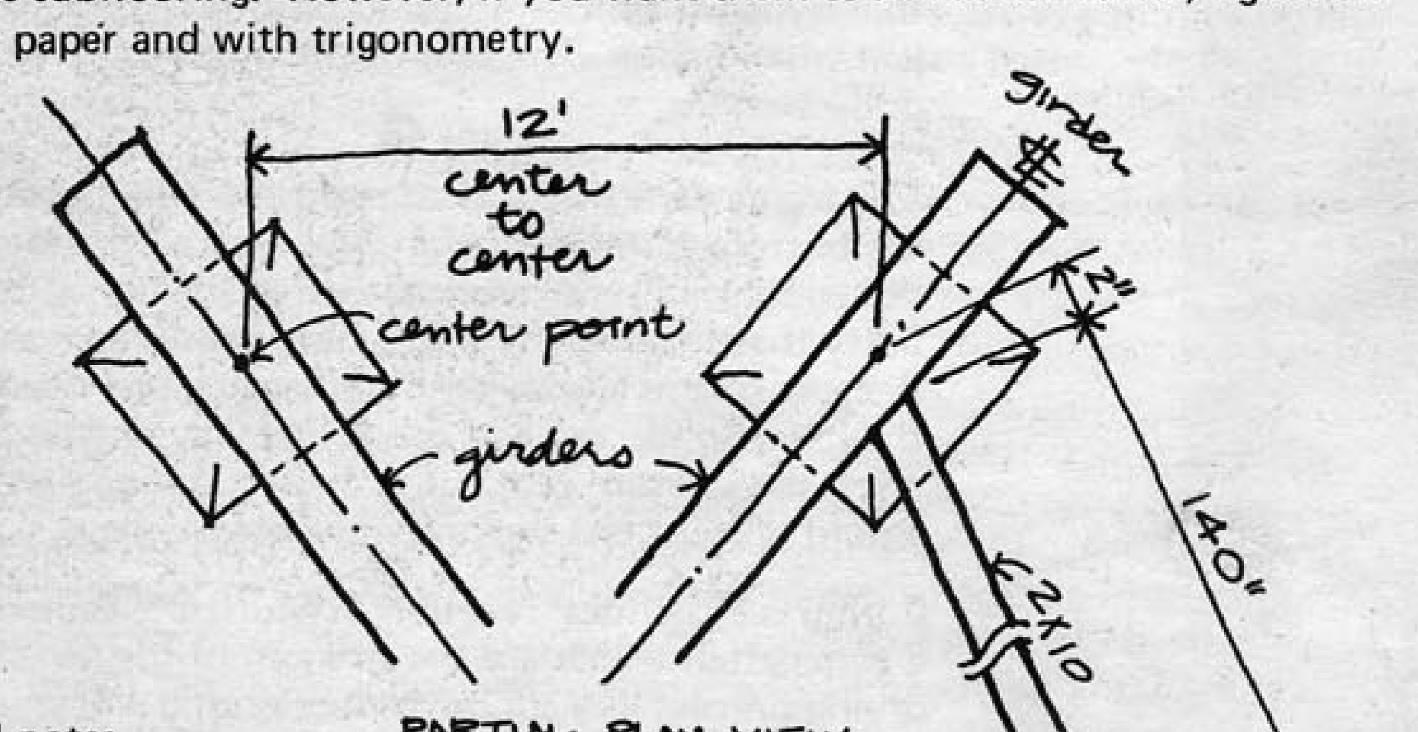
| No | Length | Size |
|---|---|---|
| 18 | 18' | 2 X 6 joists |
| 6 | 12' | 2 X 10 end joists |
| 6 | 14' | 4 X 6 girders |

6 pre-cast concrete piers
two sacks ready mix concrete for underneath piers




TOP VIEW

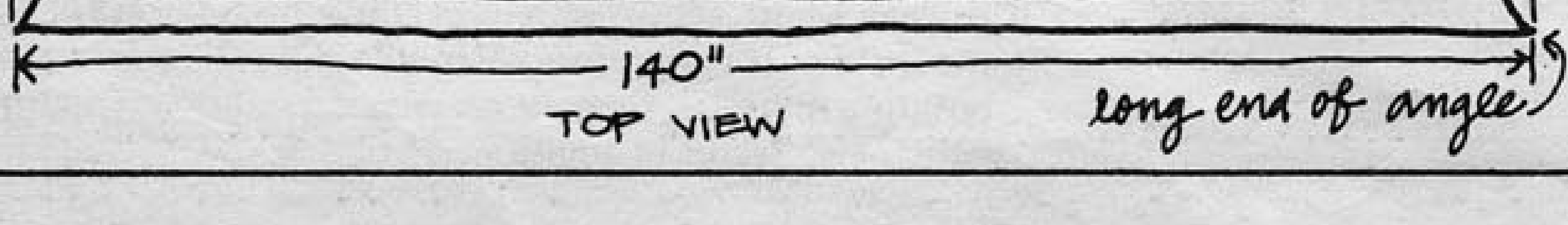
The joists can all be pre-cut to measurements as shown. When cut this way, the will be staggered when nailed on; this doesn't matter if you use the tongue and groove subflooring. However, if you want them to run in even lines, figure on graph paper and with trigonometry.



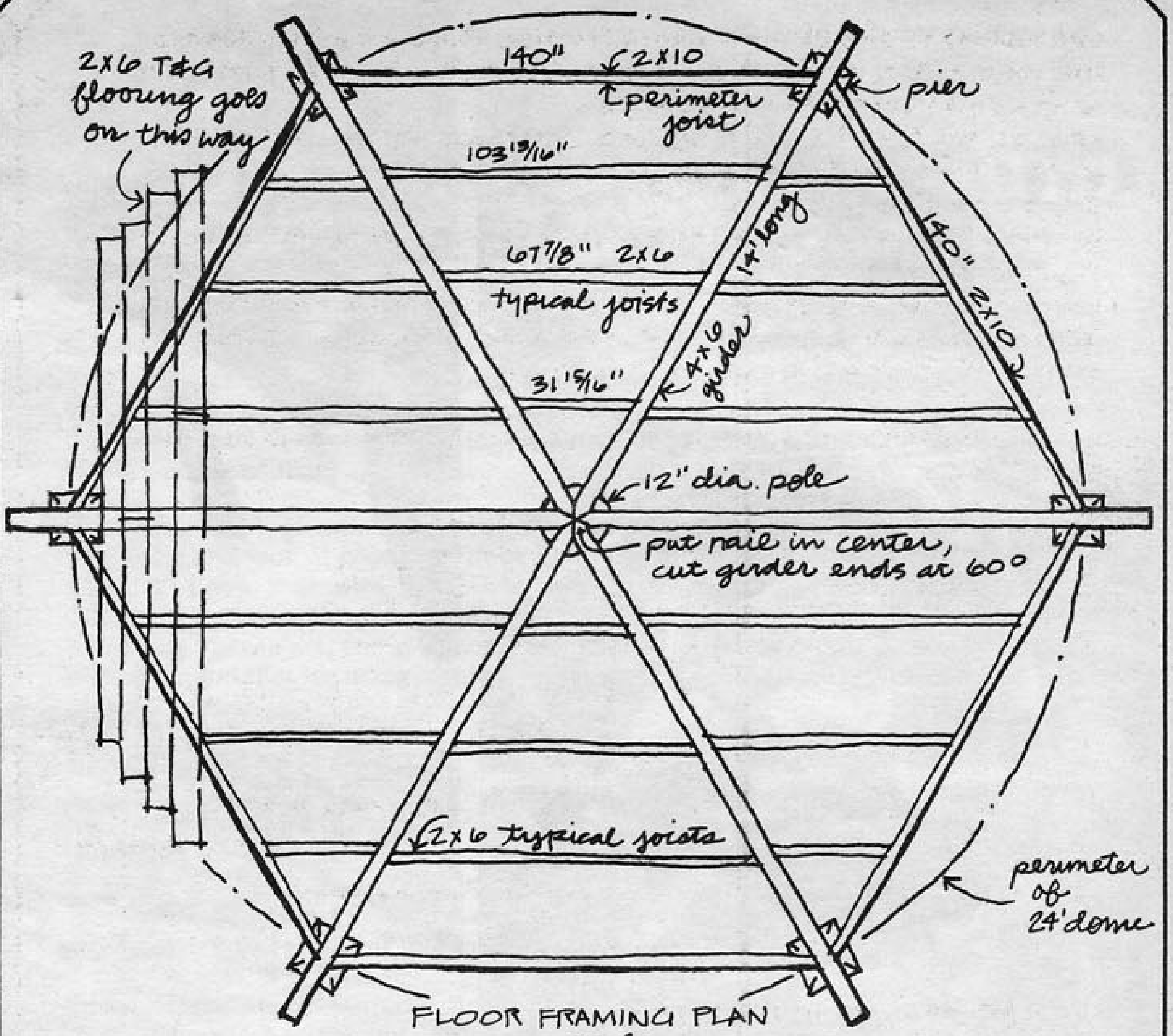

PARTIAL PLAN VIEW

Helpful note:
The joist measurements are not from center line to center line, but from one inside girder edge to another:

If you're using 4 X 6 girders you subtract 4" from the radius; this gives you length for long ends of angle.



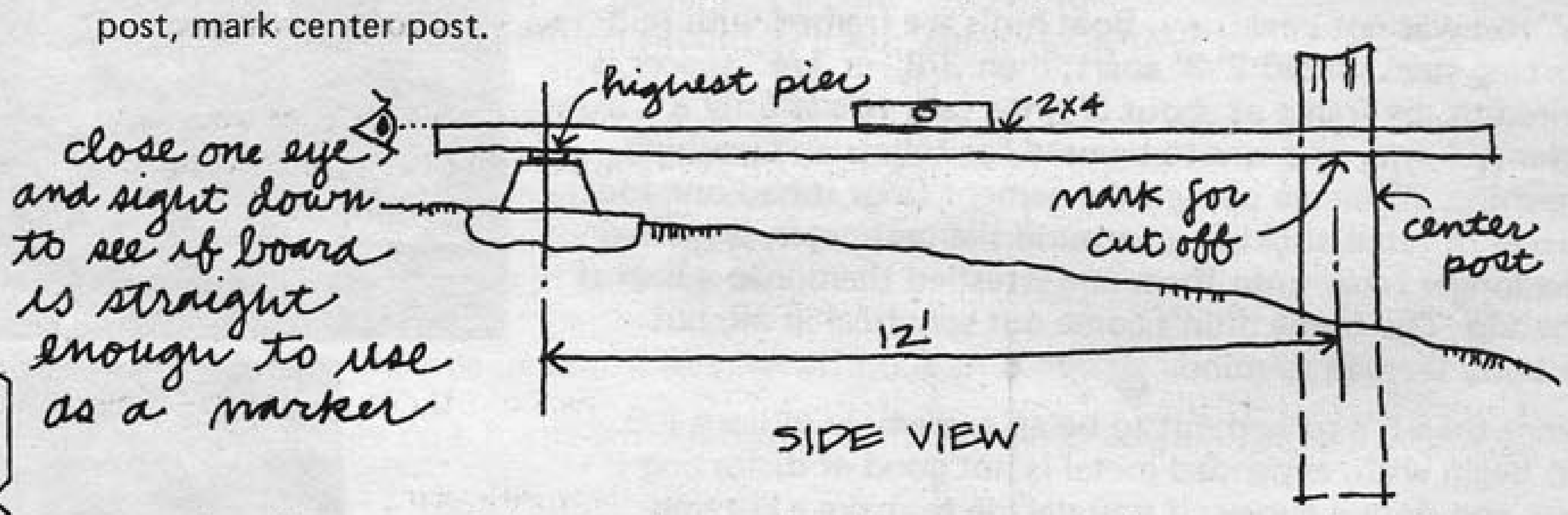

TOP VIEW




FLOOR FRAMING PLAN
no scale

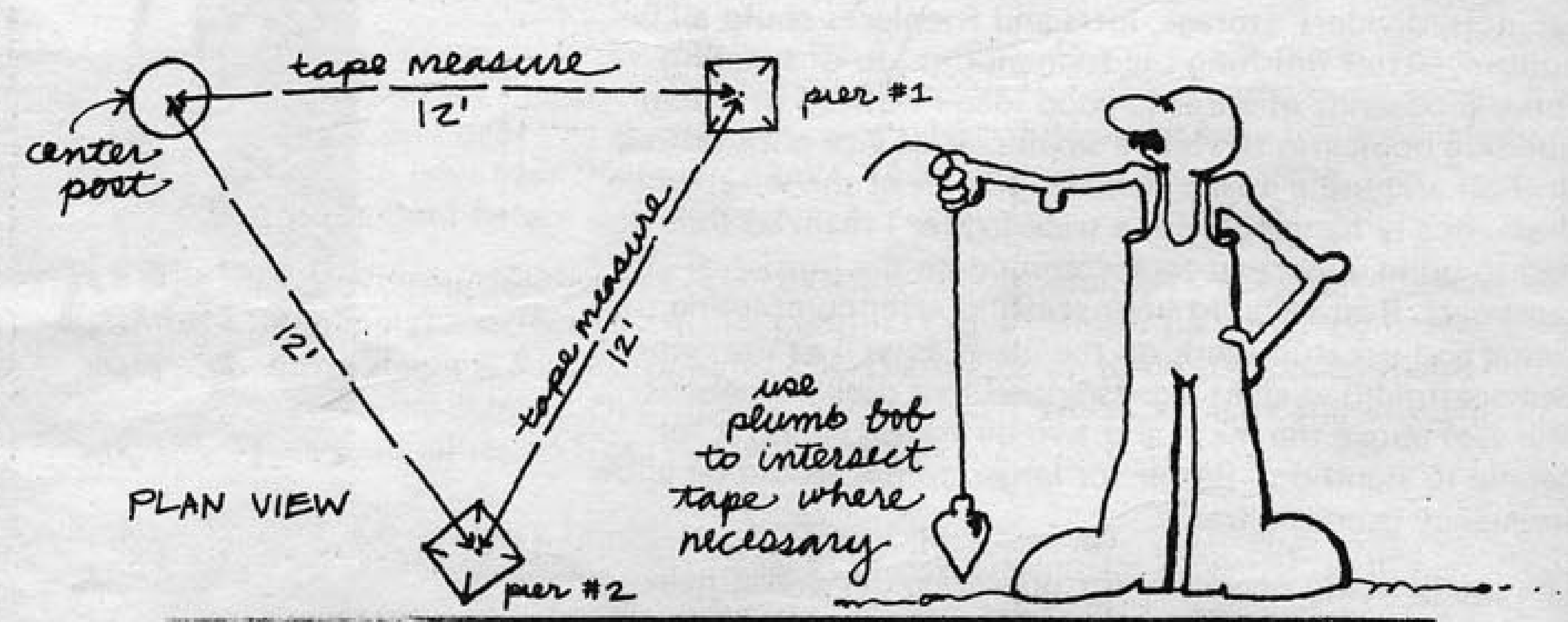
### Posts, Piers and Girders

—pre-cut your girders and joists. This can be done where there is electricity, then carried to site.
—first, set center post. Use a treated telephone pole, or a piece of fallen redwood or cedar tree. It should be at least 12" in diameter. Dig down at least 3 ft and put it in before cutting it to final level. Tamp earth hard around it, plumb with level.
—next, set highest pier 12' from center of center post. Locate the highest point using a long straight 2 X 4 with a level on top, and tape measure to ground. Dig down to solid base. If not, just rest it on hard ground. Level the top of the pier with hand level, tilting back pier and scraping down high spots with straight-claw hammer until pier top is level.
—when high pier is set, rest long straight 2 X 4 on top of pier, run it across to center post, mark center post.

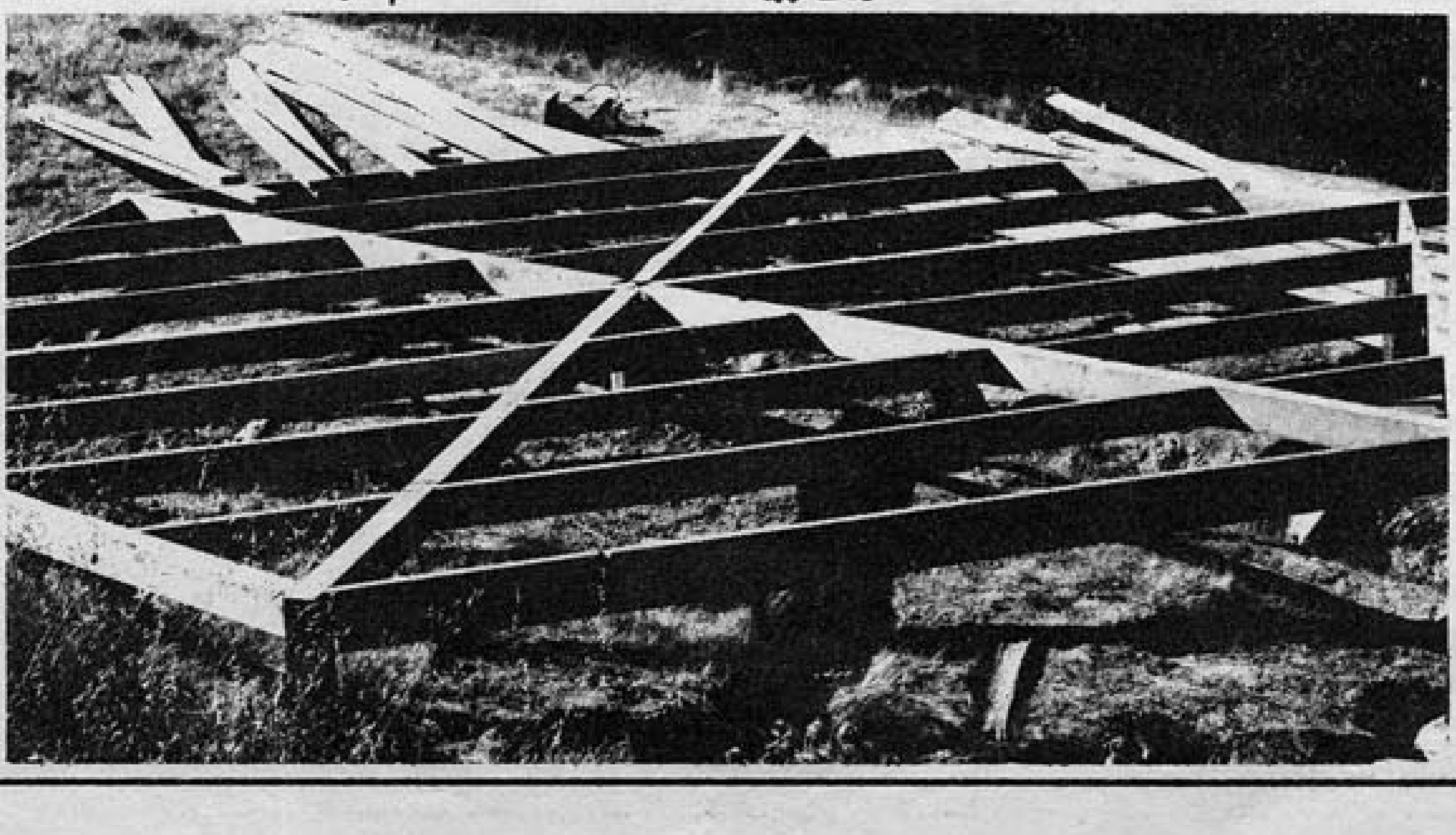



SIDE VIEW

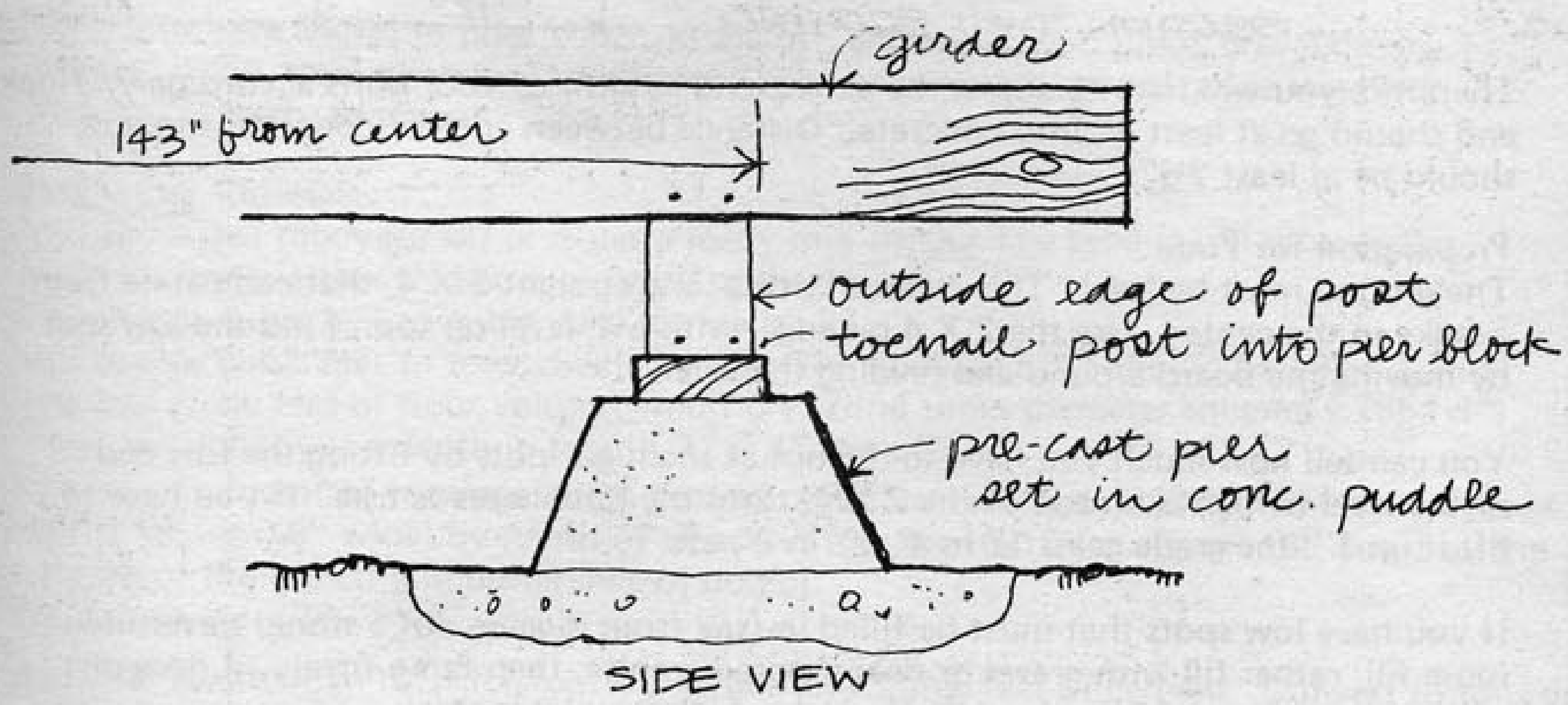
—next draw lines *around* the post for cutting. To get an even line, use a piece of cardboard or paper, curl it around the post, use hand level and eyeball to level it, draw line all around post.
—cut off post. If there's electricity, go around line with skilsaw, finish with handsaw.
—to check, rest girder on center post and pier, and set hand level on top. Bubble should be level. Remove girder.
—put nail in center of center post.
—now you're ready to locate other piers. Use two tape measures, one from center post to point above the second pier, the other from pier to pier. Or you can use two pieces of baling wire, with loops to fit over nails, premeasured to 12'. From the intersection of the two tapes, hang plumb bob to locate position of next pier.



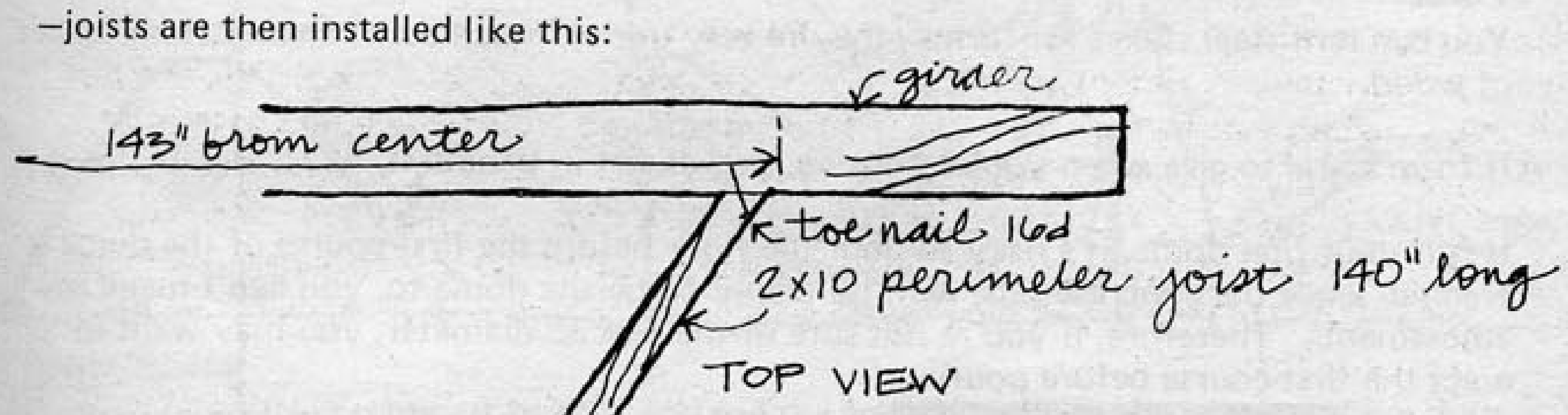

PLAN VIEW



—take a shovel, scribe a 24" square around the bob. Remove it and dig down to hard earth, making the hole about twice as big as the pier base—this gives you room for moving it around in final measurements.
—set in pier No. 2, level it. Use it and center post to get next pier location. Use the hand level to see if tapes are being held roughly level.
—keep going until all piers are set.
—be careful in measuring, double check all measurements because error accumulates as you go around.
—then, using center post, straight 2 X 4 with level on top, measure post heights. Measurement is from bottom of 2 X 4 to top of pier. If you have a transit, you can be more accurate at determining these heights.
—cut off posts
—install posts so that outside edge is 143" from center point. This will later give you the post to nail cross brace to.




—once posts are in, install pre-cut girders.
—drive a nail in at center of girders for floor center point. It may be necessary to drive a small piece of wood in first, to drive nail into.
—hook tape measure over nail, measure out 143" and mark on each girder. Mark top.
—joists are then installed like this:



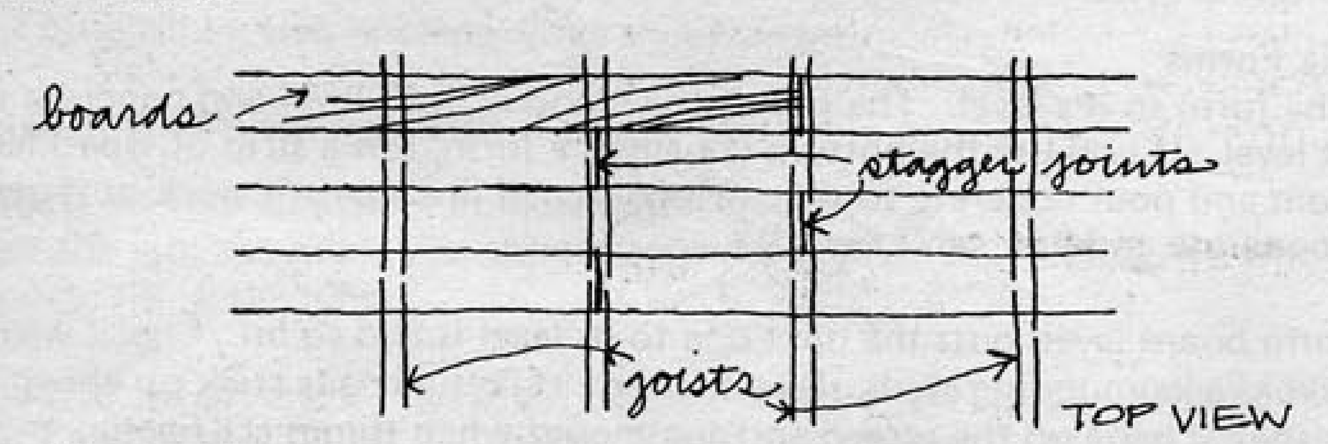

—nail outside joists on with 16d nails. Blunt the tips of the nails to prevent wood splitting.
—first nail up each joist with one nail per end. Use level to plumb posts as you go. You may have to shift piers around a bit. Nail joists to both girder and post.
—next, cross brace. We nailed on 2 X 4's.
—install inside joists.
—you can use plumbers tape for joist hangers.

**Flooring:** You should double check this list carefully; perhaps there are more efficient ways to order the lumber.

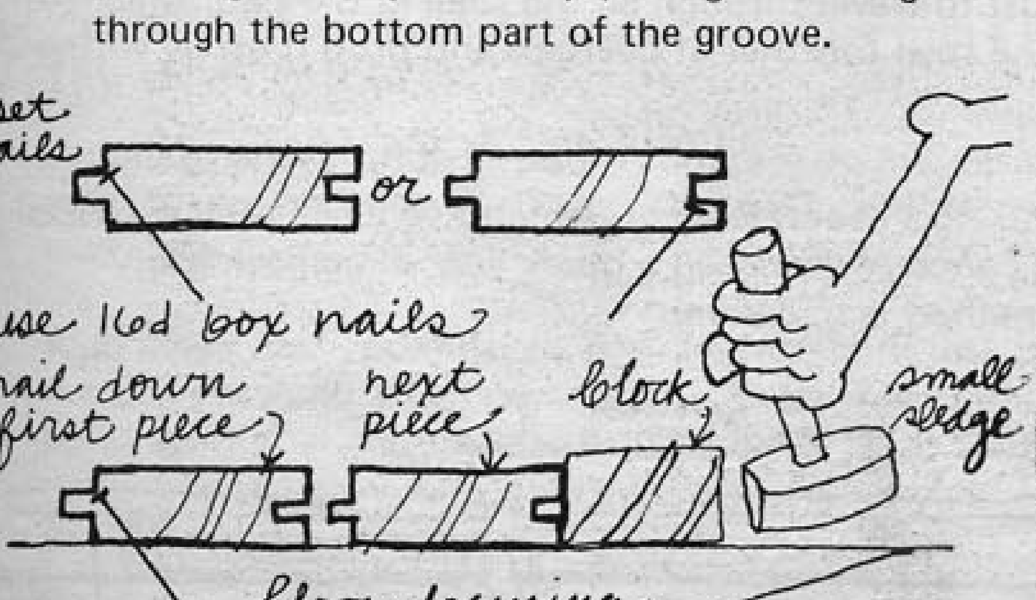
2" X 6" tongue-and-groove subflooring:

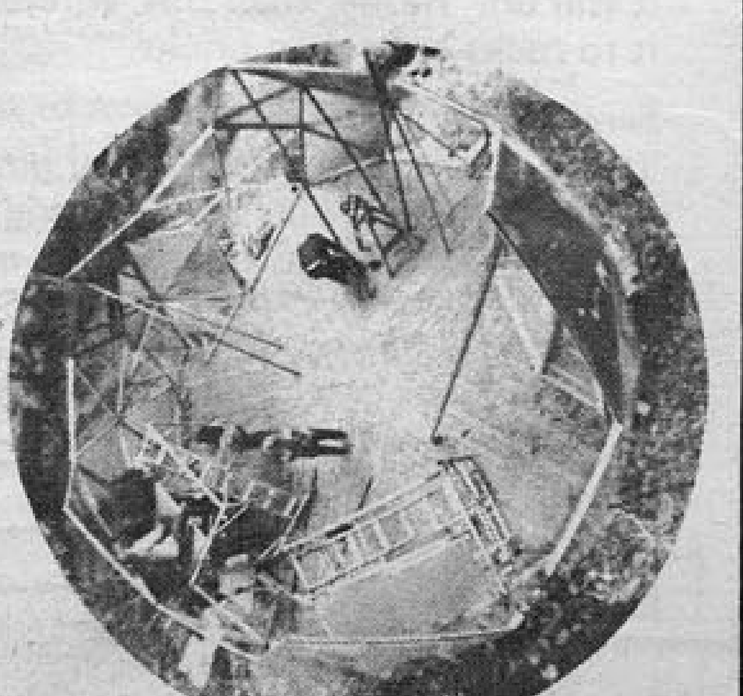
| No | Length |
|---|---|
| 24 | 10' |
| 44 | 12' |
| 14 | 14' |
| 12 | 16' |

Flooring was nailed on staggered for extra strength. If board ends are all in a line, the joint will flex.




—start nailing on flooring in the center, working towards opposite end of platform. When half of the platform is on, do other half. Let boards extend, and cut off later.
—to make sure each piece goes out to the full 24' diameter, use a piece of wire looped around center nail to check.
—to make tongues and grooves of boards mesh properly, use a small slege hammer and small blocks of lumber.
—nail diagonally, preferably through the tongure. If you nail on the groove side, nail through the bottom part of the groove.



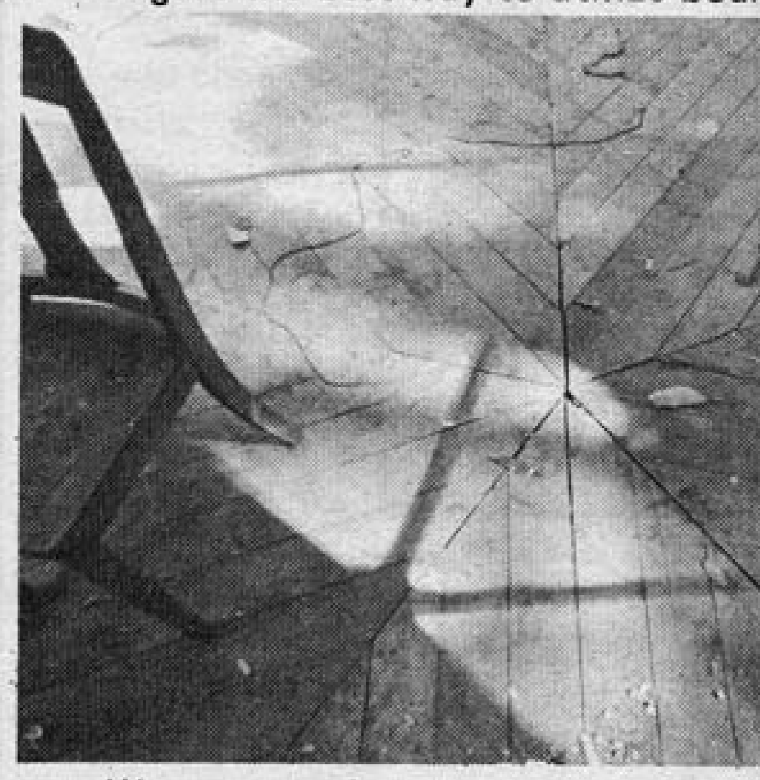



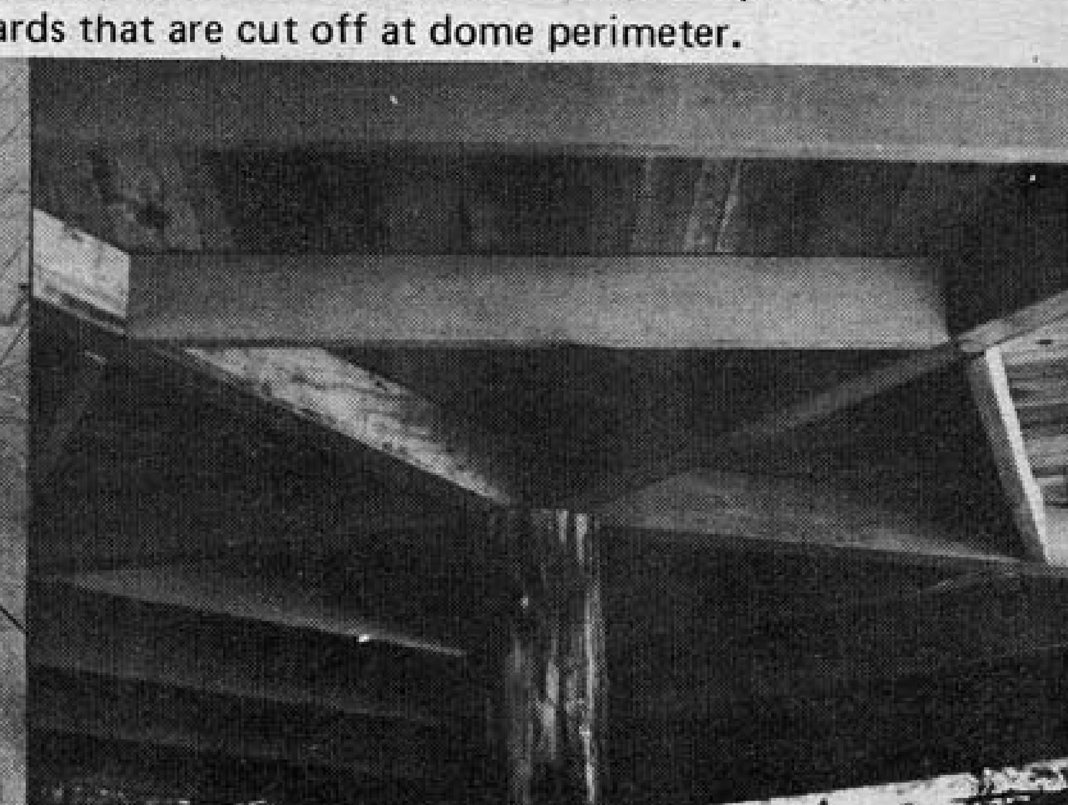
—this way no nails show on the floor surface.

## 24 FT PENTAGON TONGUE AND GROOVE FLOOR

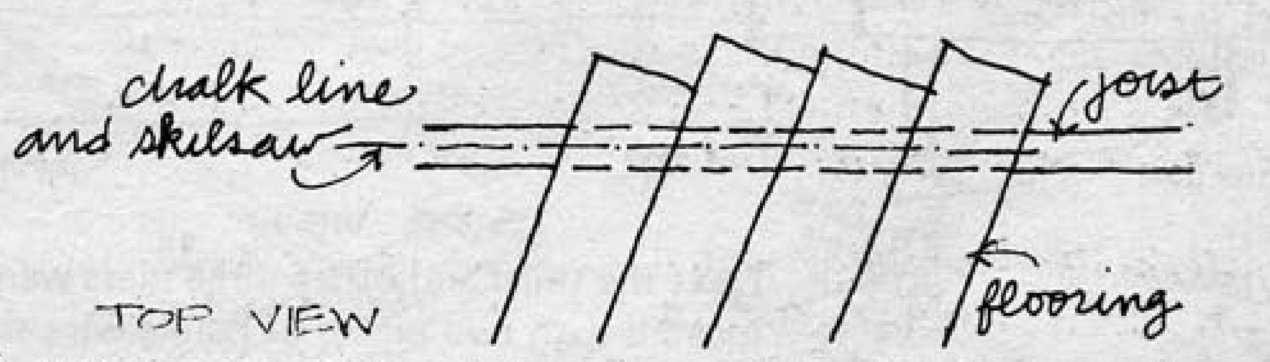
Wayne Cartwright designed and built some radial pentagon floors with flooring mitered and running out from the center. This made five triangular floor sections. It's more complex than the hexagon, more trouble to build, and beautiful. The five points of the 3-frequency dome that rest on the floor can be lined up with the five floor seams.

To figure the materials needed for frame and decking of the pentagon floor, look at hexagon plan as a reference, then use graph paper and/or trig to figure what sizes of lumber to order. There is one less pier (and girder) in the pentagon, making perimeter joists longer. Without a diagonal cross brace to hold up the center of the perimeter joist, the floor is very springy. Even with the cross brace the floor bounces a little. If this bothers you, you can put another post and pier under the center of each of each of the five perimeter joists (we didn't). We've misplaced records of what lumber we ordered. As I recall we started thinking that 90 12' 2 X 6's would do it, then changed our minds to 24–10', 18–12', and 12–16' 2 X 6's. Check for yourself. Figure the best way to utilize boards that are cut off at dome perimeter.



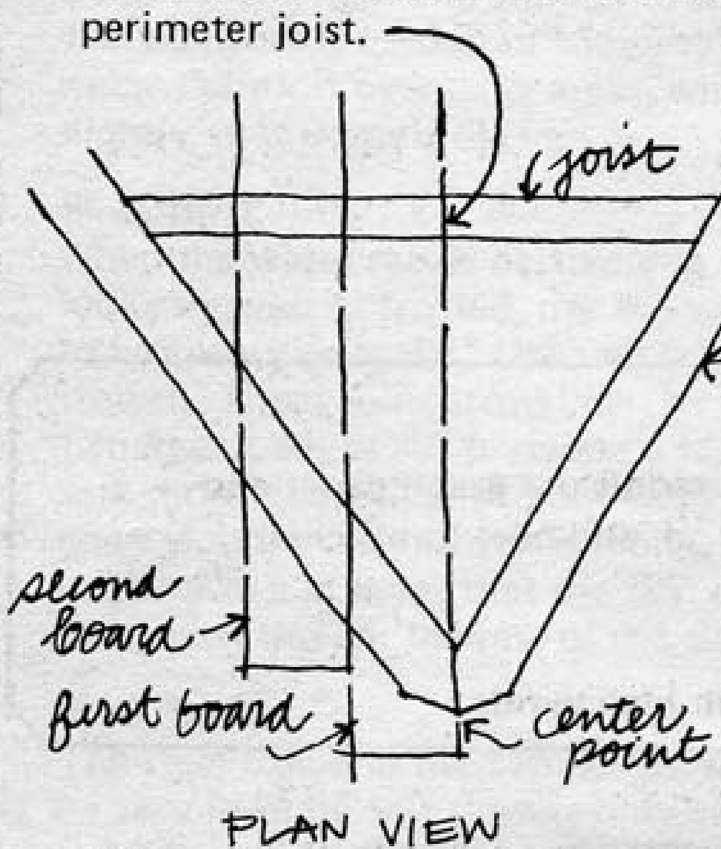


We pre-cut pieces and numbered them. It would probably be easier (if you have power) to nail flooring to girders, snap chalk line, and skilsaw off. Set blade of skilsaw so it barely cuts through flooring, but not through joists underneath.




(A *chalk line* is a small metal spool containing blue chalk powder. By pulling the string out, holding it at two points and snapping it, you get a straight line for sawing.)

In nailing you start from the middle of each triangle. Mark the midpoint of each perimeter joist.



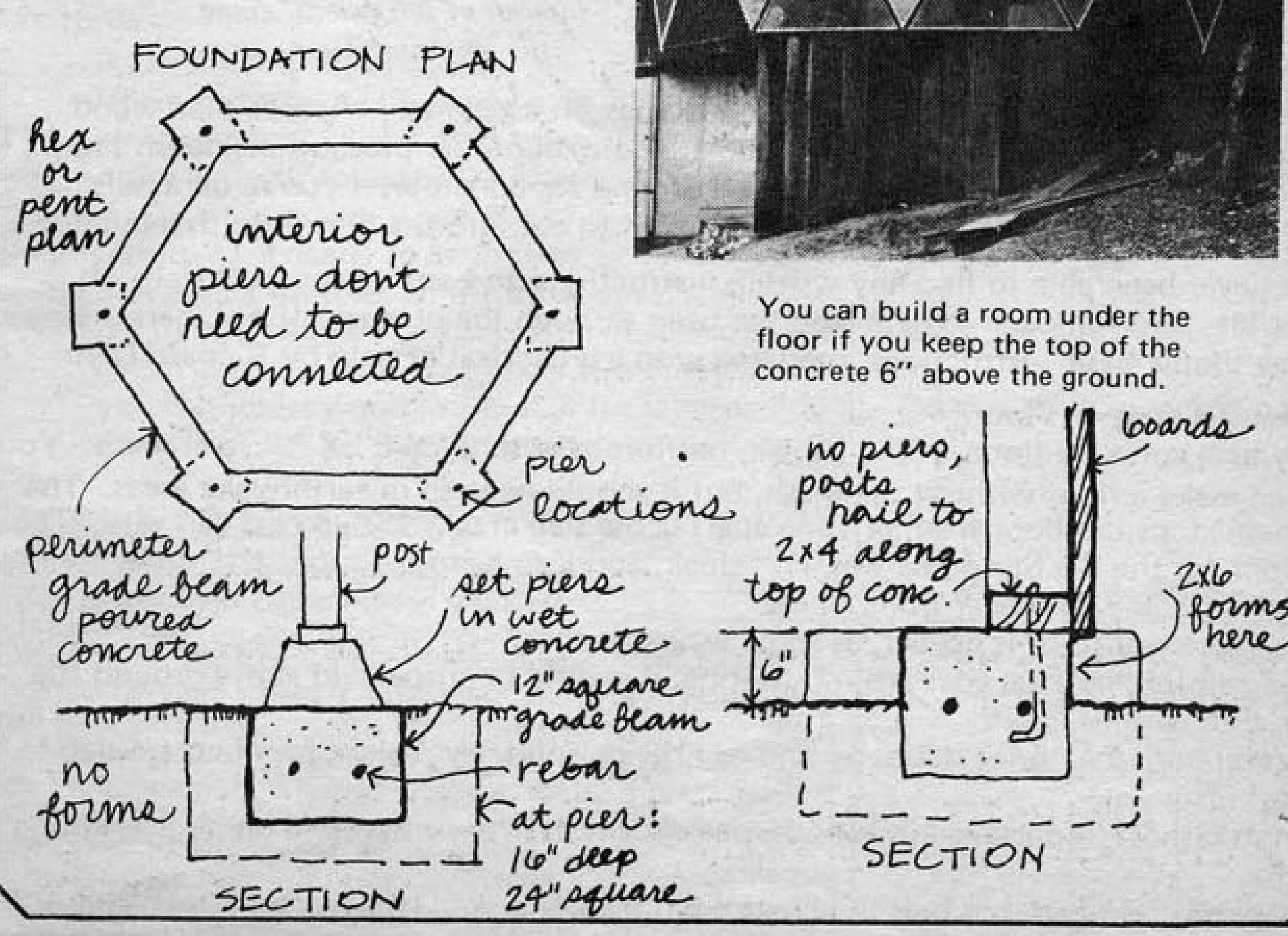

Finish planking one triangle at a time, in half sections.

Let boards extend and cut off later.

## for the building inspector:

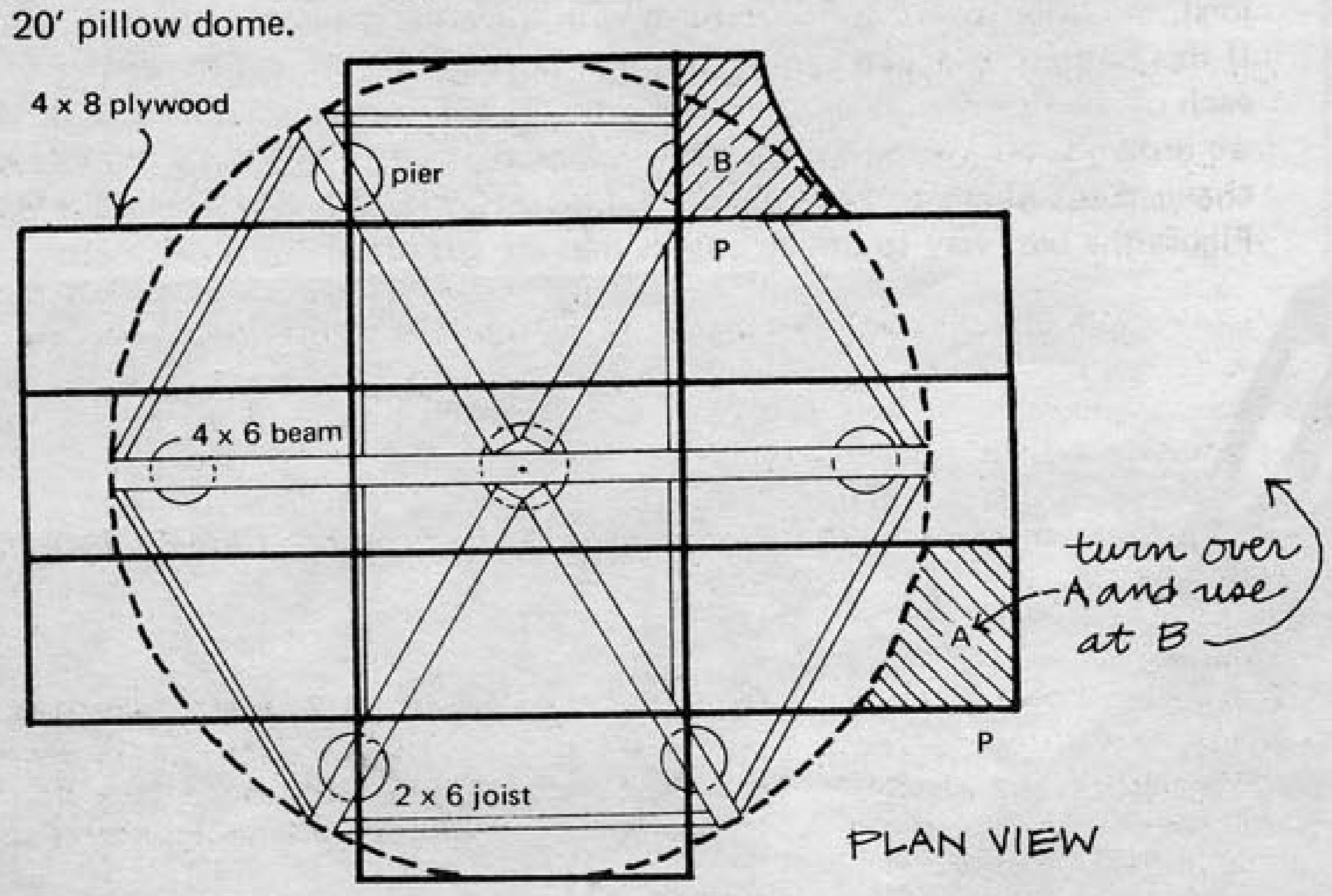
If you must get a building permit to build, the piers will either have to be checked by a structural engineer, or be connected by a continuous foundation. Easiest way is to set piers on poured concrete pads connected by a grade beam. No formwork is needed.

You can build a room under the floor if you keep the top of the concrete 6" above the ground.

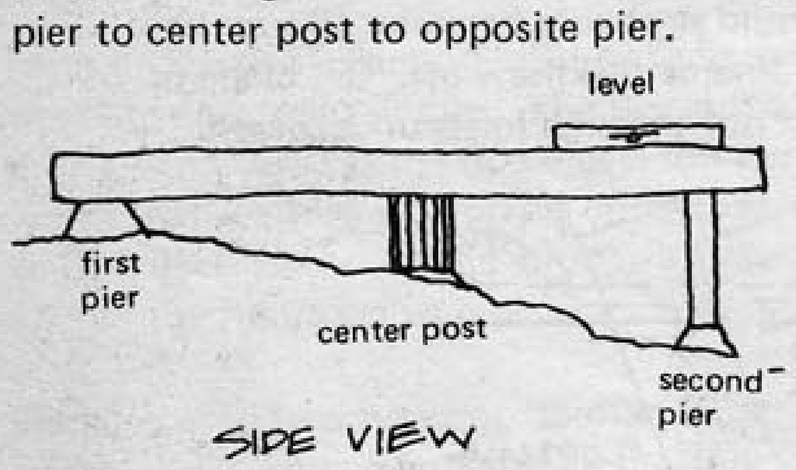


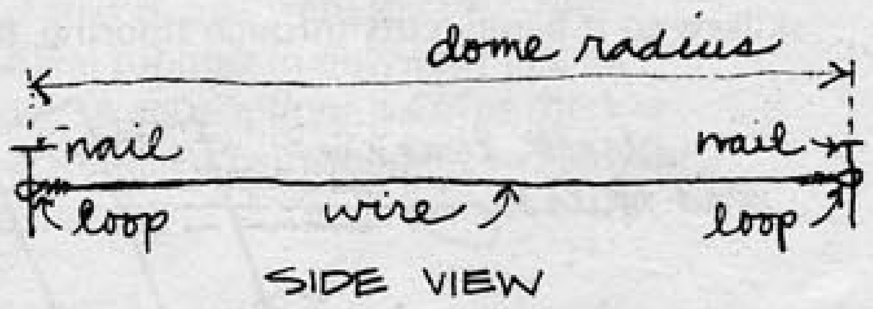
## 20 FT HEXAGON PLYWOOD FLOOR

The plywood floor is simpler—much less nailing, and very little cutting. We used *"2-4-1"*: 1 1/8" tongue and groove plywood with exterior glue. It can span 4 ft between joists and is the only flooring needed. This is the floor that Jay and Kathleen used in their 20' pillow dome.



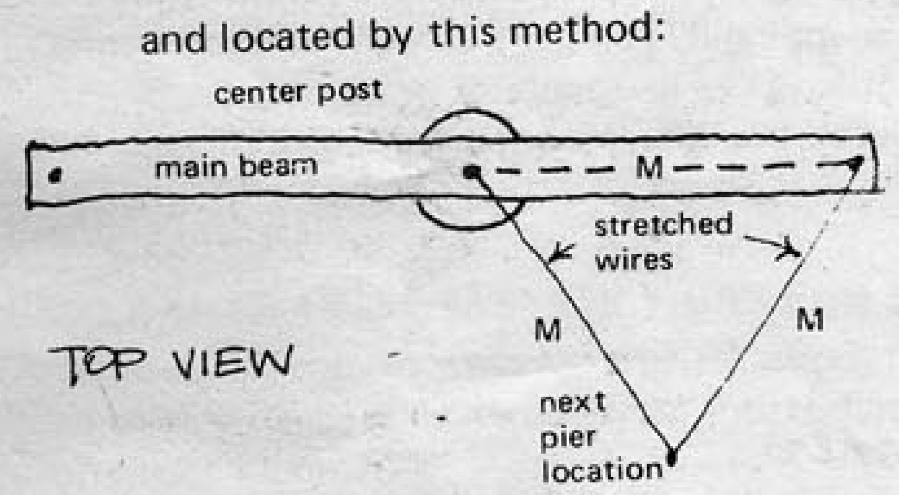

In the framing of this floor, a long (20') girder was first installed, from low point pier to center post to opposite pier.




Next the third and other three piers were located with two pieces of baling wire with loops like this.

and located by this method:

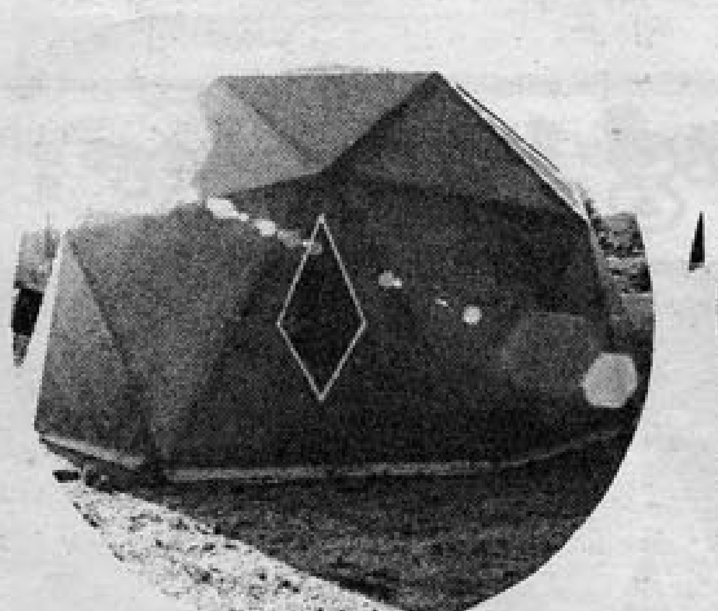



### OTHER SIZE PLYWOOD FLOORS

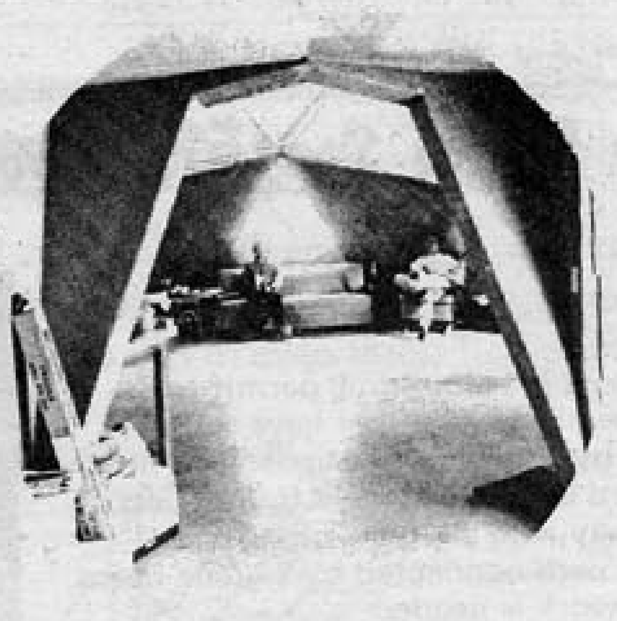
To work out a plywood floor for a dome of different radius use graph paper and scale size 4 X 8's. Determine where joists would best go, and how to efficiently use the plywood.

### ANCHORS:

Screw anchors should be used to hold domes down in high winds.



*Dyna Dome on concrete floor*



*Interior of Bill Woods' dome showing concrete floor*

## CONCRETE FLOORS

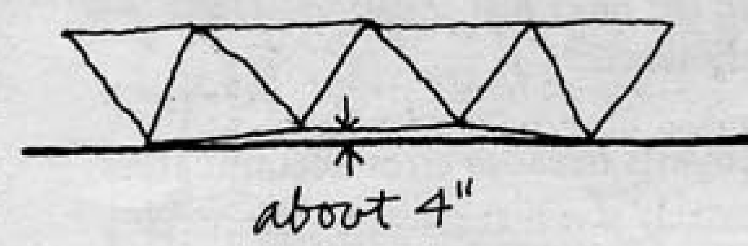
Concrete is a practical floor material for domes. It's generally cheaper than wood, provides an absolute anchor for the dome, and with proper precautions doesn't have to be icy cold. You need relatively level ground for concrete; if you're on a hillside, it's generally easier to build a wood floor than to cut into the hillside with a bulldozer.

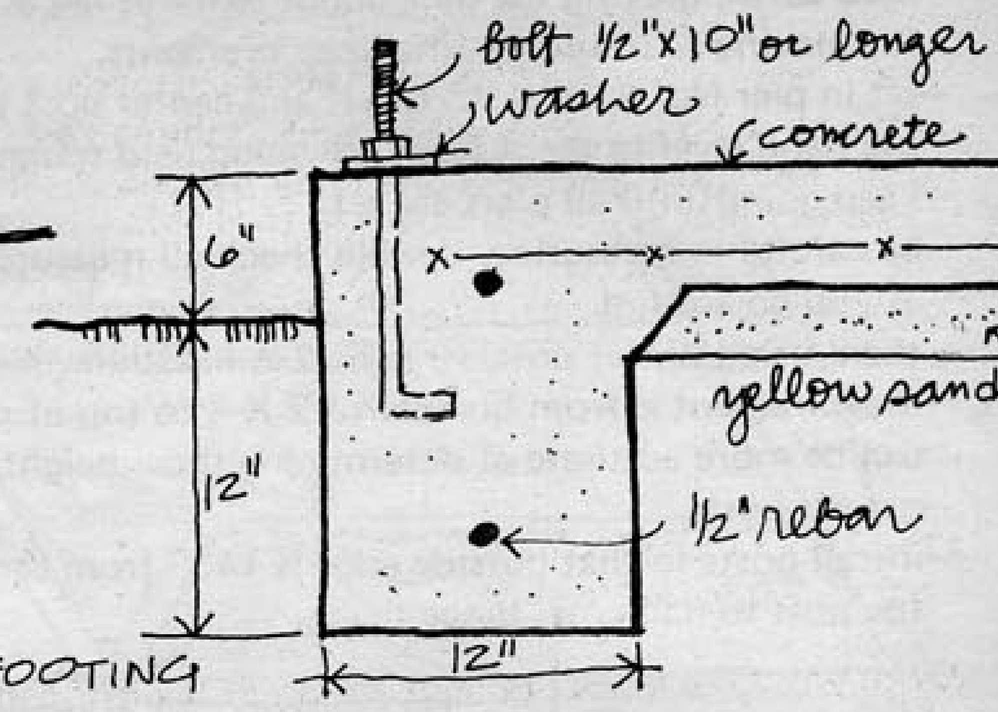
I've never been able to find any written instructions on pouring concrete slabs. If possible, find someone to help who has been through the process. If not, here are some simple basic instructions, prepared with a great deal of help by Richard Dehr.

### Typical Concrete Floor

- —typical concrete floor is 3"-4" thick, reinforced with 6" X 6" X ¼" steel mesh. You can make a floor without the mesh, but it should be used in earthquake areas. The mesh stops the floor from drifting apart if the slab cracks. Thickness can vary. The floor for the Big Sur dome was 1½" thick, and Ken Kern describes a 1" concrete floor in his book *The Owner Built Home.*
- —perimeter of floor is deeper, as some weight is there.
- —½" reinforcing steel goes around footing; it should be suspended above ground (tie it with wire to rocks).
- —gravel underneath for drainage, and to provide solid, level place for concrete slab to rest on.
- —plastic sheet important as vapor barrier. Put it over the gravel and under everything else.
- —hooked end of anchor bolt is embedded in the concrete. Use two or three ½" X 10" bolts for each strut along bottom of dome.

Remember that if you are making a 3-frequency, 5/8 sphere dome, the bottom course is not level.




Therefore you will have to adjust the height(and length) of your bolts accordingly. Hook end should go at least 8" into concrete. Distance between edge of concrete and bolt should be at least 2½".

### Preparation for Pour

The ground must be level. This is done with a long straight 2 X 4, that can rotate from a stake in the center. Use the 2 X 4 on edge, with a 4' level on top. Find the low spot by moving the board around and reading the level.

You can tell how much you have to dig out at the high spots by lifting the low end of the level (which is on top of the 2 X 4) until the bubble reads true. If you have to lift it up 1", the grade gains 1" in 4', 2" in 8', etc.

If you have low spots that must be filled in (say from digging out a stone) never use loose fill, rather fill with gravel or decomposed granite, then tamp firmly. Loose dirt will settle and leave hollows under the slab which may later crack.

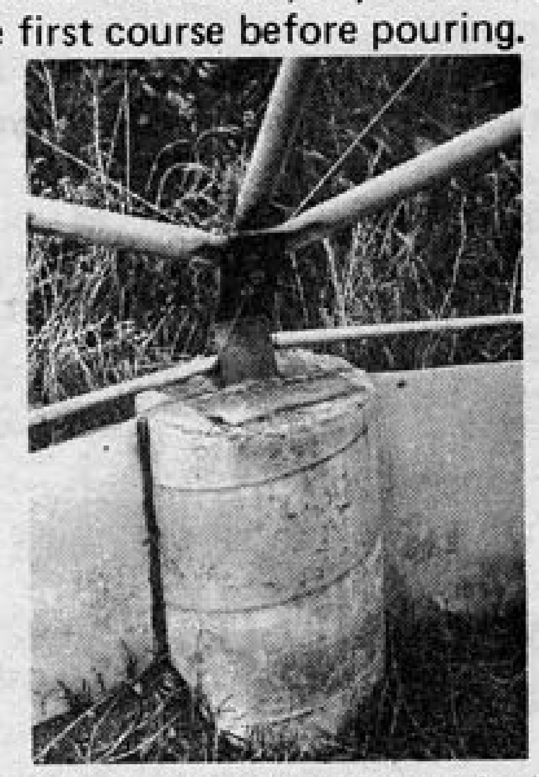
Final level can be obtained after the forms and screed guides are set by using the screed board and reading under it for level.

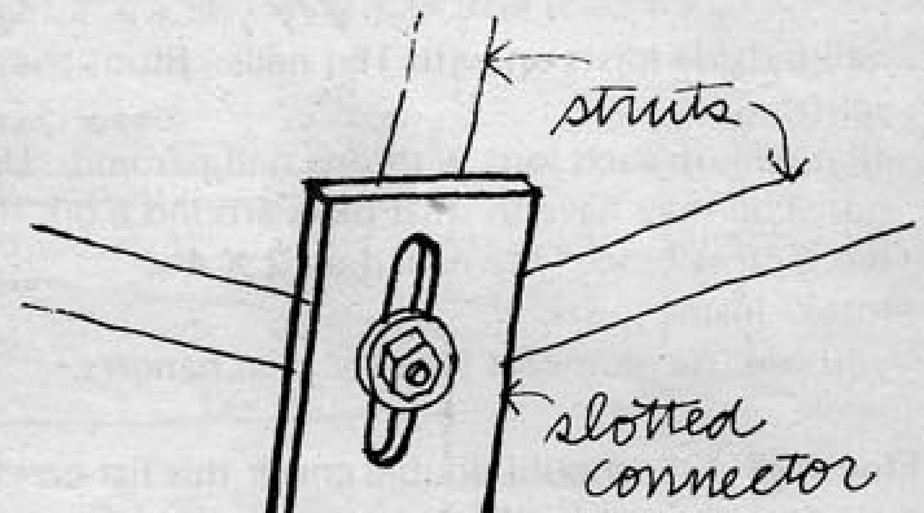
### Forms

You can rent steel stakes for forms—they're very useful, much easier than making stakes of wood.

If form starts to give when you're pouring, shovel dirt in behind it.

If it is your first dome, it's risky to pour the floor before the first course of the dome is erected—once the concrete sets, with bolts in it to tie the dome to, you can't make any adjustments. Therefore, if you're not sure of the precise diameter, you may want to erect the first course before pouring.






*a slotted connector like this gives you some play*

An alternative method to the typical form shown above would be to erect the bottom course of the dome, and use the base triangles as forms. After first course of dome is in place, arrange it so that the center of each ground strut is an average equal distance from the center, get each of the five hubs touching the ground to be at the same level, stake it in place so it can't move. Leave an opening to wheel concrete in. Drill holes in base struts, suspend anchor bolts and prepare for pour as described.

### Positioning Forms

Position the form so it's level. The top of the wood is floor level and concrete is poured up to that level. If you use the bottom course as a form, run a strip of wood level with bottom and pour concrete to that strip(A pencil line doesn't work as it gets splashed with wet concrete and you can't see it).

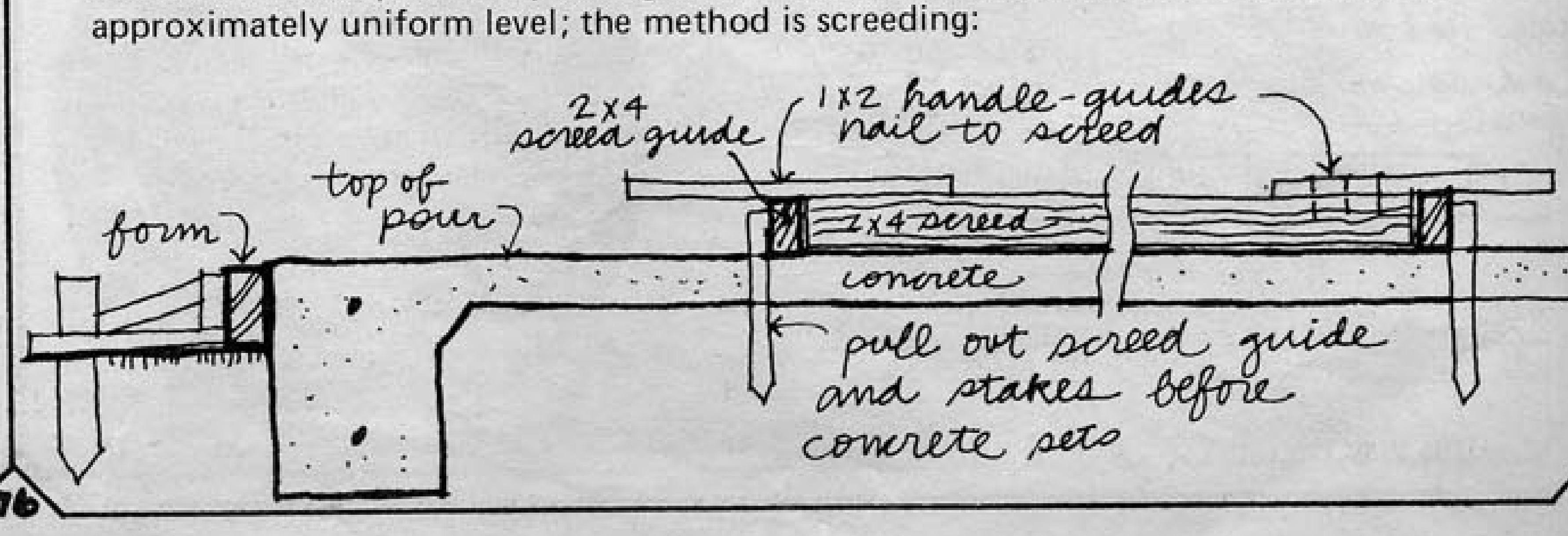
Set one form board level, butt the next one to it, level it and so on. Check with the long 2 X 4 to avoid accumulating error. Don't let any stakes or nails stick up above the form boards, as they'll hang up the screed and cause grief when things are hectic.

Once the form is level, no tightrope acts or anything that will change the level or push it out of line.

Setting the rebar is very important. The reinforced foundation supports the weight of the building, and anchors it. There should be no steel in contact with the ground. For example it's fairly common to drive stakes of rebar into the ground to wire horizontal rebar to; this provides a path for rust to travel through all the steel in the slab, which it will do. Rather than this, wire the steel together at overlaps and prop it up by wiring it to rocks or broken bricks.

### Screeding

This is a very important part of pouring a concrete floor, which I've never seen described in a book. Once you start pouring concrete you need a quick way of achieving an approximately uniform level; the method is screeding:



The bottom of the screed board is at finished floor level. The 1 X 2 handle guides slide on top of the screed guides.

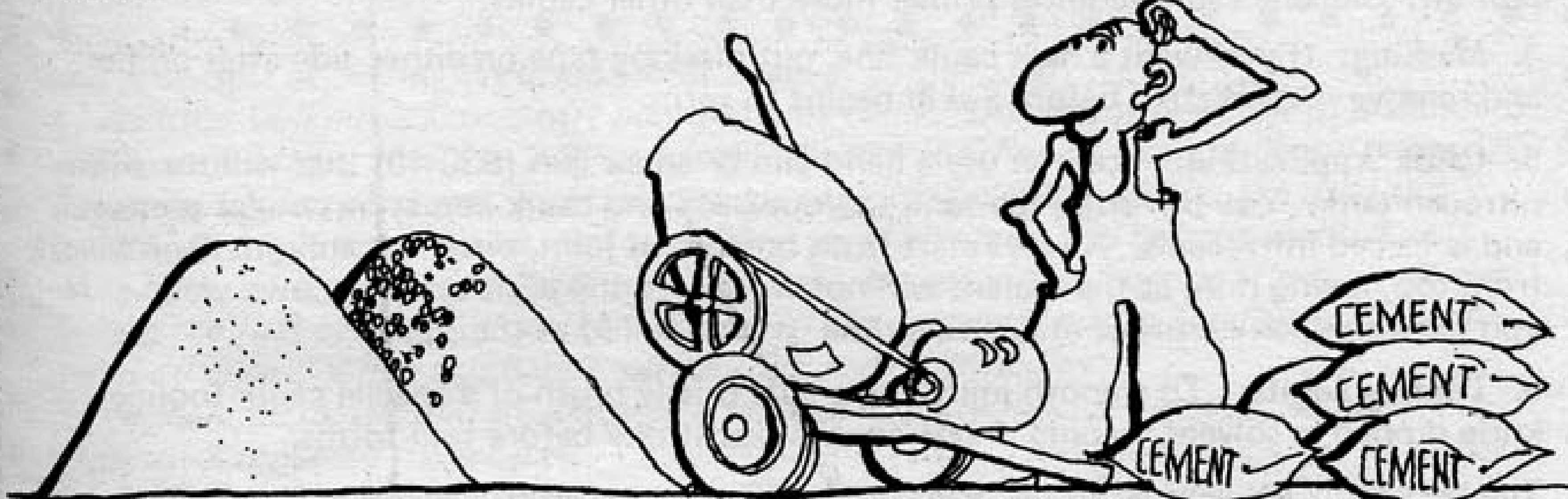
Note: when screeding between the screed guide and the *form,* one guide bar runs on the screed guide, and the bottom of the screed board runs along the top of the form. You'll see this if you mentally pick up the 2 X 4 screed board in the above sketch and move it over to the left, to screed the section next to the form.

As the concrete is poured, two men move the 2 X 4 back and forth—wading through the concrete with rubber boots on—and it levels the concrete, ready for final troweling. The push-pull action of the screed is very important, as it won't work to just pull the screed along.

Keep a flat-nosed shovel and rake handy to remove concrete if too much is dumped in front of the screed.

**Once you have a level to pour concrete against, anchor bolts in place, gravel down, plastic on top, steel mesh on top, reinforcing steel in trench, screed guide installed, etc. you're ready to pour.**

**Estimating Materials**
You can either mix yourself or order a ready-mix truck. The sand-gravel mix, or the concrete comes either by the cubic yard or by the ton.
—to change cubic feet to cubic yard, divide by 27
—to change cubic feet to tons, divide by 20. (Someone said this should be 13)
—to find cubic feet of floor volume: multiply .7854 times diameter squared (.7854 $d^2$) and multiply by the depth in feet (4/12 if 4" deep floor)
—to figure content of footings (ditch around perimeter) multiply width of trench in feet (as 8/12 for form 8" wide) by depth of trench in feet (as 16/12 for a form 16" deep) by the length of the trench (circumference of dome)
—perimeter of circle: $2\pi r$ (2 x 3.14 x radius)
add total for floor to total for footings to get total cubic feet of cement. Convert to tons or yards.




**Home Mixing**
If you mix yourself, convert to tons and use the following table to determine how many sacks of cement to order, depending on how rich a mix you use. (1:2:4 is common for floors—that means 1 part cement / 2 parts sand / 4 parts gravel)

**Mix Proportions**

| Cement | Sand | Gravel | Total Mix of These | Constant |
|---|---|---|---|---|
| 1 | 2 | 3 | 1:5 | 4 |
| 1 | 2 | 4 | 1:6 | 3½ |
| 1 | 3 | 4 | 1:7 | 3 |
| 1 | 3 | 5 | 1:8 | 2½ |

Rent a big mixer, ½ sack or larger. Full sack is best. Don't mess with small underpowered mixers, as the first part of the pour will be setting up before you've poured the last. Get a contractor's wheelbarrow with pneumatic tire for carrying concrete from mixer to floor.

It's important not to let the materials in the mixer get dry so that they pack. When water is added to a pack like this it takes much time to penetrate and slows things down. Therefore, keep careful track of how much water you use for the mix; then begin adding water first.

Try to get a 55 gallon drum, with hose slowly filling, and two buckets to dip water. Or have a hose filling two buckets while shovelling.

First water, then gravel, then sand. Cement last.

**Ready Mix (Concrete Delivered in Mixmaster Trucks)**
The larger the job, the more you should consider ready mix. A standard truck can hold 7 yards, six in the hills.

You should avoid getting a "hot mix"—a load that will set rapidly. One of the features of concrete is that it will not set while mixing, but if set time has passed while in the truck, you can end up with several tons of unwanted and very hard concrete. To avoid this, make sure the driver comes to the site beforehand so he doesn't get lost. Make sure he has washed out his last load, so it doesn't catalyze your load.

Get all the advice you can from the driver, in fact you can let him help run the pour. Most of what I know about concrete came from Bud Golden, a truck-driver from Monterey who delivered 12 truck loads of concrete to us while we were building a huge house. Each time he would arrive with a load we'd let him run the job—he'd tell us what to do.

**Pumping:** It's possible to pump concrete up hill, or in to inaccessable sites—as much as 250 ft from the road. It may cost $50 or more and be well worth it. Ask the ready mix company.

With ready mix you must be prepared to work fast, especially if the weather is hot. A truck has about 20 ft of chutes; if that's not enough to reach, you may have to build additional chutes, or wheelbarrow it from the truck, in which case you'll need ramps. With heavy wheelbarrows-full have a helper running backwards, holding the front.

The main thing is to be ready before the truck arrives. You usually get 45 minutes per truckload before they charge overtime.

**Pouring**
Three is a good size crew, more is better. One on mixer or guiding truck chute, two working with concrete, alternating on wheelbarrow and leveling. Have floats and finishing trowels ready.

Use gloves, lemon juice, or some kind of oil on your hands before the pour for protection. Concrete will crack your skin.

If you haven't used a plastic ground sheet, wet earth before pouring. This gives you more time to work. Start early in the morning and keep moving. If concrete starts to set before you're ready you have problems.

Dump concrete in place, screed off level.

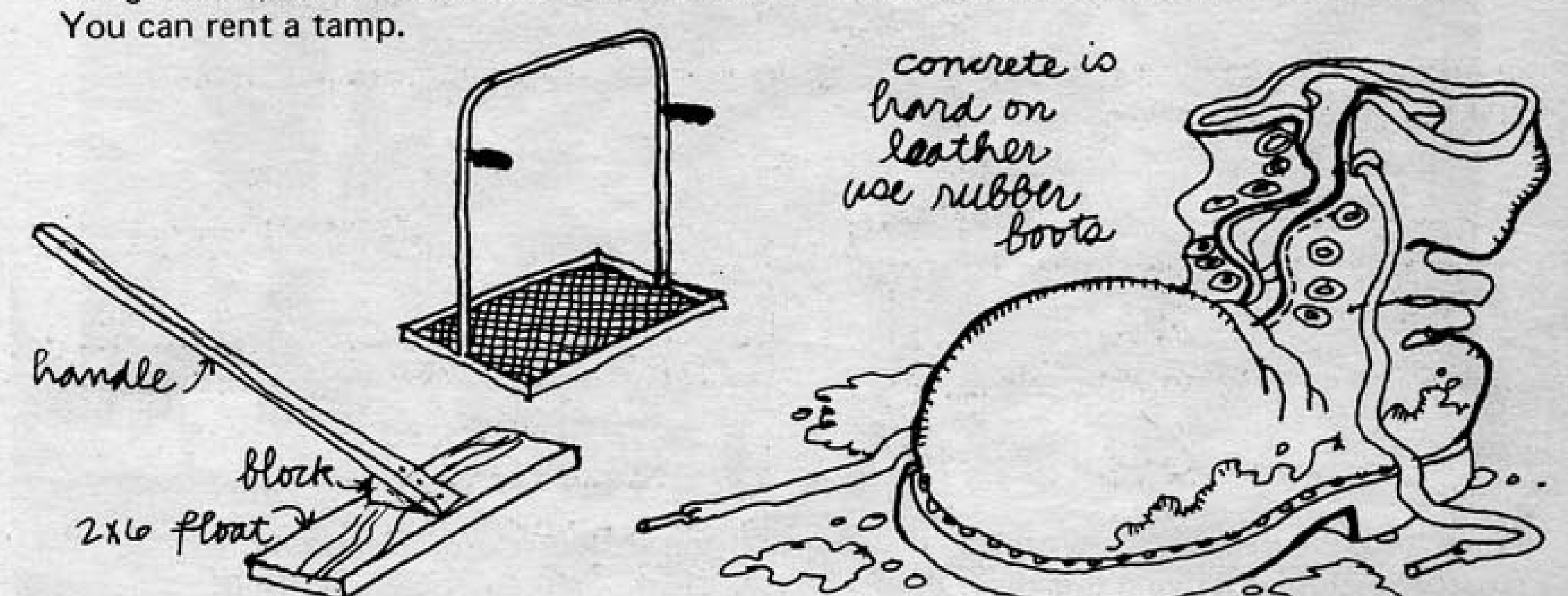
If you use steel mesh, pull it off the ground as pouring progresses. Do this with 4' hook made of rebar—reach through the concrete and pull it into the middle of the slab.

Keep checking anchor bolts so they're upright and at proper height to grab ground struts.

If you stop for lunch clean tools off.

Take a stick and puddle the footings—poke concrete up and down to fill any voids in the trench.

**Tamping**
A tamp is an angle iron frame about 10" X 45" with a 3/4" mesh expanded metal screen welded to it, and waist level handles. Tamping pushes the gravel down from the surface so it won't get in the way of troweling. It helps to level the slab and brings water, sand and cement to the surface. Tamping is done right after screeding. You can rent a tamp.




**Bullfloat**
You can rent a bullfloat or make one of 1" or 2" by 6" board about 12" long with a 1" X 2" handle long enough to reach the center of the slab from the outer edge. The bullfloat is used after tamping to get an even flow of the mixture of sand, cement water. Work it over large areas, while the concrete is still wet. Lift the leading edge slightly so it doesn't dig in.

**Woodfloat**
When the water raised by tamping and bullfloating begins to absorb and the surface looks sugared or frosted, use the woodfloat. It's a slab of wood with a handle—cheap to buy, easy to make. Use two trowels, one to lean on while reaching, the other to trowel. The leaning trowel can be the steel trowel to be used later. You should have two kneelpads of ¾" plywood a ft sq. You are ready to wood float when the pads don't sink more than ¼" with your weight on them. Work in sweeps to obtain excess. A good woodfloat finish, or a spongefloat finish is an OK bonding surface for tile or brick. Keep in mind that the first part of the pour may be ready for woodfloating first, even though the rest of the slab is still wet.

**Steel Trowel**
The steel trowel is used to polish. seal and waterproof the slab. The slab should be very level by this time as only very small defects can now be corrected. The slab is ready for the steel trowel when the trowel raises a polish and the kneelboards make little or no mark on the surface. Again, use a trowel to lean on. Lift an edge of the trowel so it doesn't dig in.

If an area is too dry, position the steel as flat as possible and move in a fast 1 ft diameter circle, pressing hard. This will draw water. If not, sprinkle water on, with a little cement.

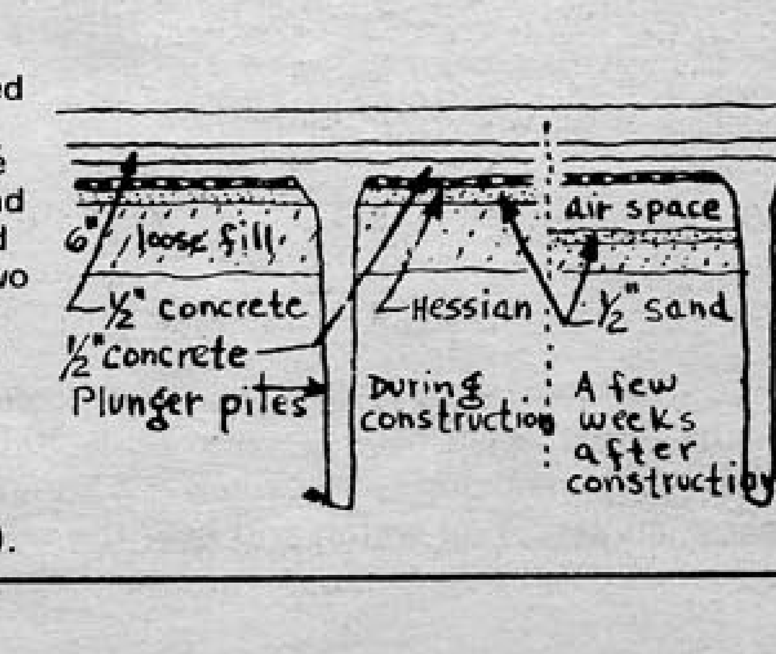
You can get a variety of finishes, including a floor that is troweled too smoothly, which will invite later spills. You can get a slight texture by working up some moisture by the circular flat trowel motion, letting the suction under the blade draw up slight ridges.

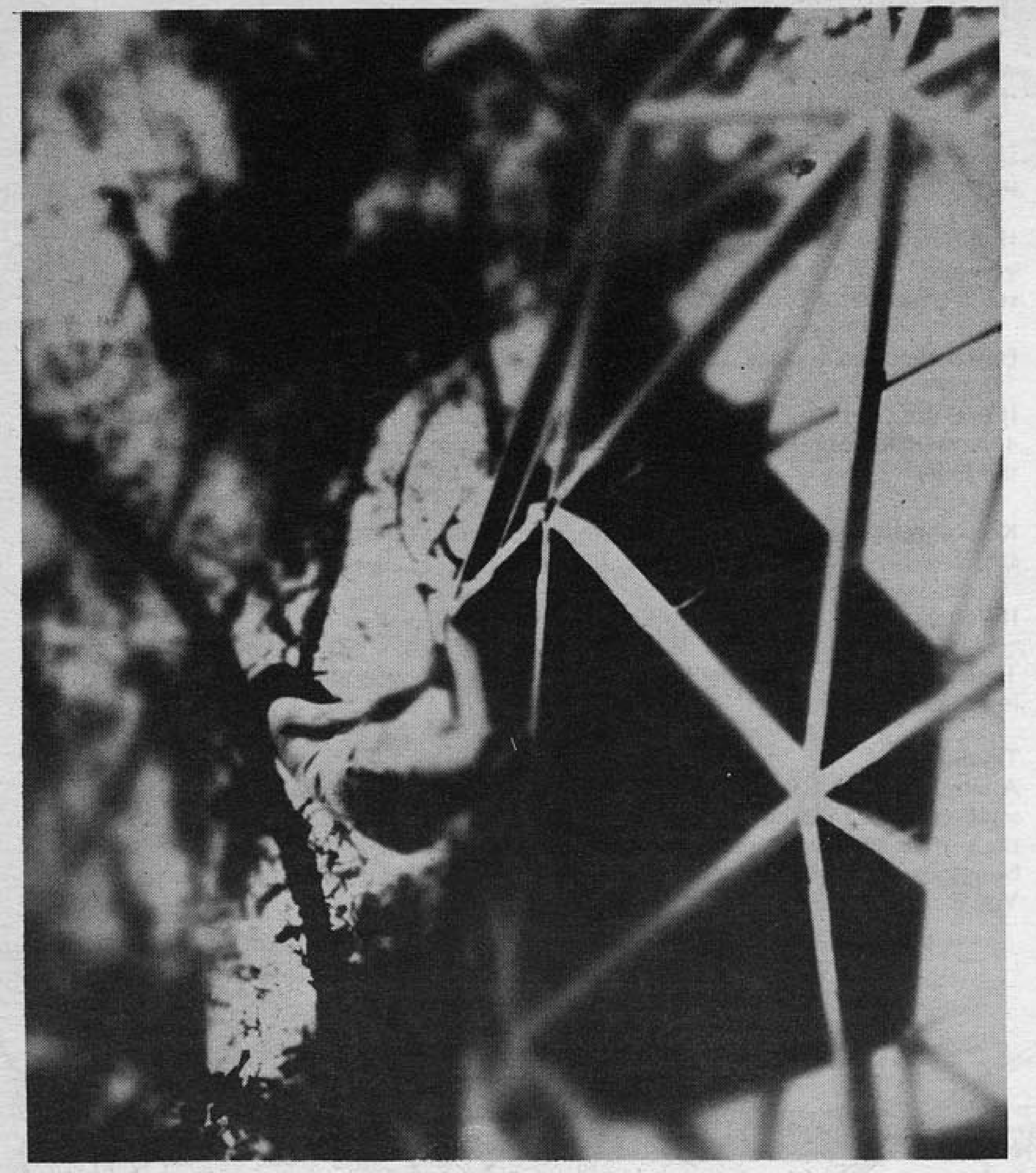
**Handy Hints**

—if kneelboard sticks to slab, pry up one corner with the steel trowel to break vacuum.
—floats and trowels must be perfectly clean. Old cement or rust makes them useless.
—an edging tool can be used to go around the slab at the edge of the form boards to make a nicely rounded transition. This tool is used when the slab is still quite wet.
—if you suspect you'll run out of daylight get floodlights.
—put up a barricade to keep stray people and pets off the curing slab.
—don't walk on the slab for three days.
—try to cover the slab with plastic or fabric and keep it wet for a few days, especially in hot weather, as it is stronger if it cures slowly.
—you can insert wood in the slab for later nailing-to. Do this by driving 16d nails in 2 X 4's. Then put wood in concrete, nails down.

**CONCRETE FLOOR**

This is a lightweight concrete floor described in *The Owner Built Home* used in India. It is 1" thick, rests on plunger piles, which are formed by driving a crowbar into the ground 3' deep. They are spaced 3' on centers, and then filled with fine concrete. There are two layers of concrete, each ½" thick, spread over Hessian, a type of burlap. After a few weeks the loose earth filling settles, leaving an air space under the slab, which is held up by the piles. The floor reportedly took a load of 450 lbs per sq ft(most building codes require 30-50 lbs per sq ft minimum).





# SEALING

When you live in a dome you become aware that the structure around you more closely resembles a living organism than a house. It is a mathematically derived membrane containing and protecting life inside; it breathes: expands and contracts. It loosens up in the sun, tightens when it's cold. When you build a dome of many pieces, as opposed to a one-piece monolithic shell such as ferro cement or foam, you must seal the seams.

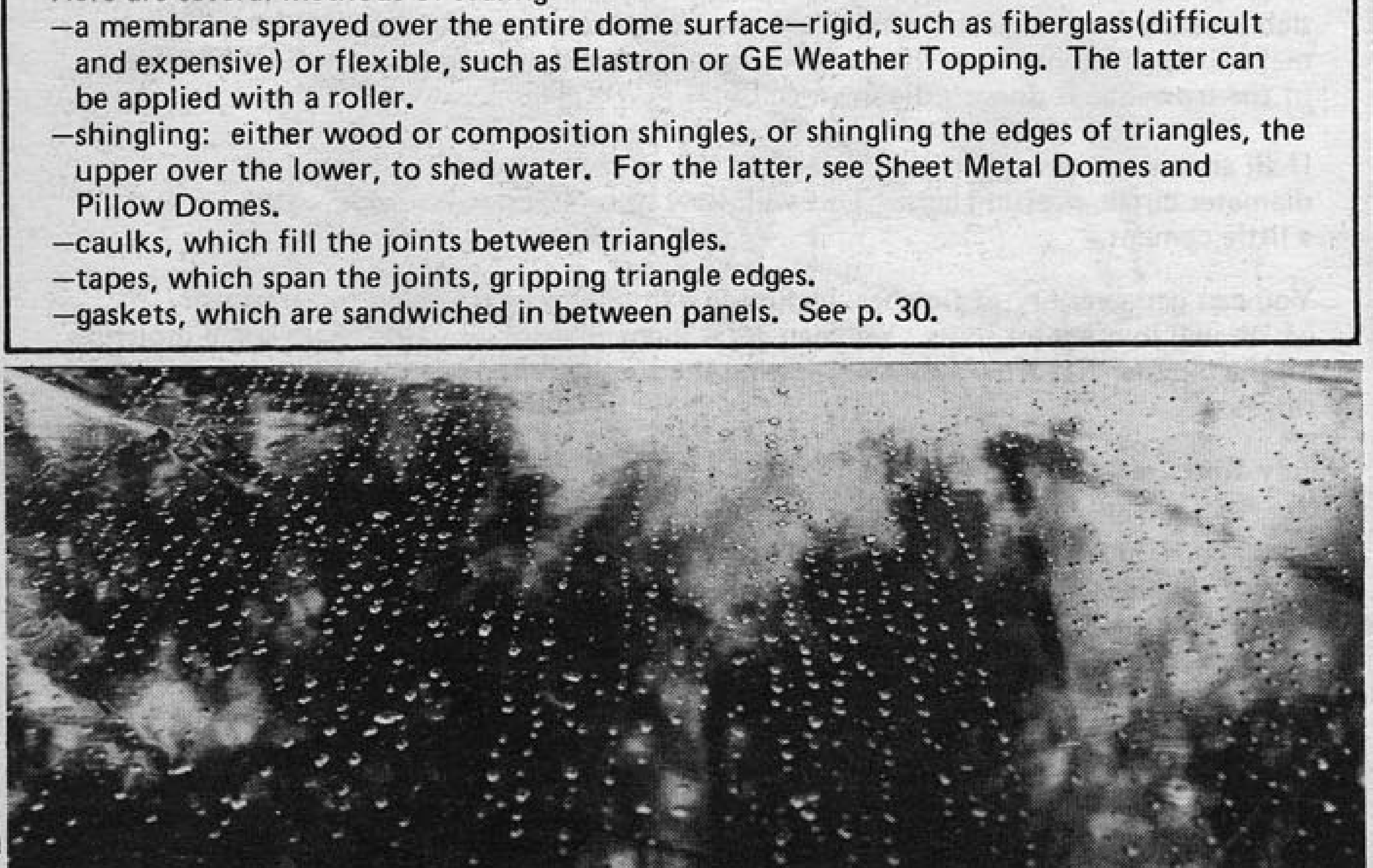
This is critical, as the entire dome is *roof*—water pours over the whole surface. Think carefully about sealing. If you don't do it properly at first, you'll end up spending four times as much time, energy and money in getting a watertight seal.

Because I was in too much of a hurry in sealing our dome, it rained *inside* during the first rain storm. It was a traumatic experience to have our floor and belongings covered with water in the middle of the night. The three of us ended up huddled in a dry spot on the floor in the least wet sleeping bag. Later I remedied the leaks, but it was a hassle.

Probably the main reason there are not more dome homes is the problem of leakage. Many of the early Pease plywood domes leaked. Communes like Drop City, Libre, Lama had dome leakage, and some of them have now resorted to shingling their plywood domes.

We've had a good deal of leakage problems, and have learned a lot about waterproofing, of necessity.

Here are several methods of sealing:
- a membrane sprayed over the entire dome surface—rigid, such as fiberglass (difficult and expensive) or flexible, such as Elastron or GE Weather Topping. The latter can be applied with a roller.
- shingling: either wood or composition shingles, or shingling the edges of triangles, the upper over the lower, to shed water. For the latter, see Sheet Metal Domes and Pillow Domes.
- caulks, which fill the joints between triangles.
- tapes, which span the joints, gripping triangle edges.
- gaskets, which are sandwiched in between panels. See p. 30.



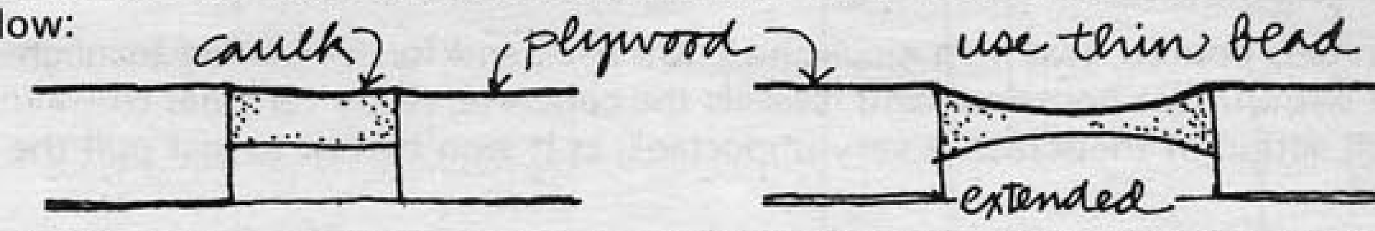
We're living in redwood country where it rains 60-80 inches per year. One of the finest things about a dome is being inside when it's raining, especially if the dome has a good deal of clear triangles. You watch and hear the rain falling, and if you're dry it's cozy

**CAULKS**

Caulks must be flexible enough to allow for dome movement, yet not pull away from edges it is adhered to. If caulk is used in conjunction with paint or tape, you must check chemical compatibilities. A good caulk is not enough; you also need a properly designed joint.

**1. Principles of Joint Design**

Expansion-contraction difficulties are minimized by designing joints that are wide and shallow:

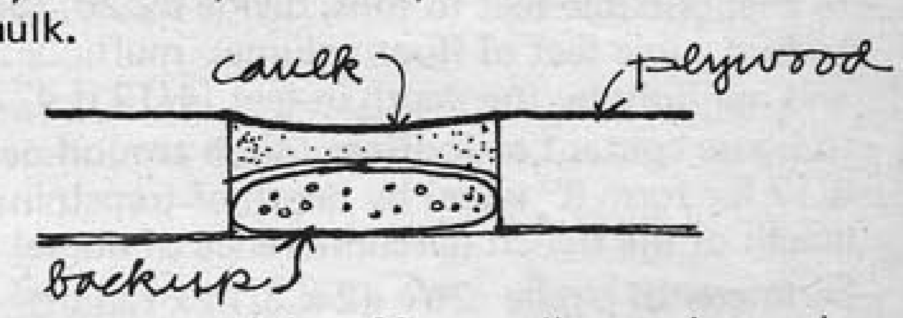



The *depth* of the sealant should be less than ½ its width. A shallow joint can cut the amount of caulk in half, and a thin bead will allow more stretching than a thick bead. The joint *width* should be at least four times the calculated maximum joint movement. Some builders use a router over dome seams after plywood is nailed on, routing out ¼" groove, then installing a back-up strip before caulking. Recommend depth for GE silicone sealants is 1/8"-3/8".

**2. Bond Breakers and Back-up Materials**

Bond breakers and back-up materials are used to prevent the caulk from sticking to a third side, to reduce joint depth, and to give the bead of sealant a concave surface:

A concave bead is best for expansion and contraction.Suitable back-up materials include PVC foam, sponged polyurethane, polyethylene foam, ethafoam, or metal foil. Be sure the back-up strip is compatible with the caulk.




**3. Priming:** Bonding surfaces must be sound, clean and dry. Most caulks require a primer. Edges of plywood are bad for caulk adhesion, as there are often bits of sawdust which pull off. Silicone caulk requires primer more than other caulks.

**4. Masking:** If you want a neat caulk line, put masking tape on either side after primer, and remove immediately before a *skin* begins to form.

**5. Caulk Application:** You can use a hand gun or an air gun ($30-40) that will run off a nitrogen tank. You can strap the tank to your back and caulk comes out under pressure and is forced into seams. Always start from bottom of joint, *pushing* caulk in. Don't work from top, laying it in, as the sealant will not work into the joint under its own weight. If you have an open cartridge at quitting time, stick a nail in at the tip.

**6. Tooling Joints:** To smooth joints use a soft bristle brush or a special caulk tooling knife dipped in solvent, wiping in one continuous stroke before skin forms.

The best caulk we've used so far seems to be GE silicone 1600, a two-part sealant that is mixed, then applied with a closed tube gun.

For double protection you might try a sealant *with* tape. Caulk would have to be applied perfectly smoothly to avoid air pockets in tape. With silicone caulk, you might use cloth or paper tape with GE Silicone Weather Topping.

We have had experience with these four basic types of caulks:

| Type Caulk: | Free Information from: | Ask for: |
|---|---|---|
| Silicones | General Electric Company<br>Silicone Products Dept.<br>Waterford, N. Y. 12188<br>Rhodorsil Silicone Sealant<br>Rhodia, Inc.<br>600 Madison Ave. N.Y., N.Y. | Brochures on *Silicone 1600 / Silicone Weather Topping / Silicone Traffic Topping / Silicone Rubber Roofing Systems / Silicone Weatherproofing Systems / Silicone Sealants for Construction Uses* / Special Data Sheets on *Silicone Series SCS 1200 & 1600.* |
| | Dow Corning Corp.<br>Midland, Mich. 48640 | Brochures on *781 Silicone Building Sealant* Sheet on *Seven Steps to Sure Sealing* |
| Polyurethanes | Dupont | Brochures on *Imron* |
| Polysulfides | 3M Company<br>Adhesives, Coatings & Sealers Division<br>3M Center<br>St. Paul, Minn. 55101 | Brochures on *Weatherban 101 One-Part Sealant* |
| Acryl-R Narrow Joint Seam Sealers | Schnee-Morehead of California<br>Box 2465<br>Santa Fe Springs, Ca. 90670 | Brochure on *Narrow Joint Seam Sealers 5504/5505 5505/5507/5516* |

In the first rains it looked as if the domes were working. The white and brown domes say they're OK. Green dome says they have just a few leaks. A week later, heavy rains and disaster. Kelly and Melodie's faces are drawn. Brown dome leaking, white dome unlivable. Mako woke up with his bed full of water. The aluminum dome which I insisted on taping with blue tape is a sponge. I'm afraid to go to meals. Spirits are low. The domes had dried out in the heat of the summer, and the caulk had failed. A few days later, we get together, decide we'll barnstorm to waterproof. Retape aluminum dome with pipe wrap tape. Martin gets a crew to put roofing paper on the purple dome, and Richie, Mako and Chris begin putting liquid rubber on the white dome seams. They end up getting it in their hair, clothes, and gluing their fingers together.

## TAPES

1. **Rigid:** fiberglass tape has been used with varying success by different plywood dome builders. In many cases it seems to develop hairline cracks. Bill Woods of Dyna Domes has successfully used fiberglass matt to seal seams. The Dyna Domes system consists of fiberglassed plywood panels, nailed to struts. Then a mixture of resin and thickening powder is used to fill the seams (ask Lloyd Fox at Douglas and Sturgess—see p. 86—for the best thickening powder). The mixture is applied with a tapered rubber squeegee so that seams are perfectly smooth.

Over that is applied a 4" strip of 1½ oz matt with resin. The strip is cut from a roll of matt with a heat knife that feathers edges, so that you don't have noticeable tape edges.

I don't know if the success of this method depends upon the plywood itself having a fiberglass surface or not.

2. **Flexible:**
   a) Elastron: Elastron No. 870 is a two-part elastomer rubber that is applied over the seam with a paper tape. It's probably the best stuff to use over failing seams.

   United Paints manufactures Elastron(see p. 86); they also make flexible waterproof membranes that can be sprayed over many surfaces, including polyurethane foam.

   b) Celastic tape is being used on plywood domes by Geodesic Structures Inc. in New Jersey over a joint first caulked, then covered with masking tape.

3. **Pressure-sensitive Tapes:** this would be an answer: an easy-to-apply tape, no sticky adhesive needed, no caulk. We haven't found such a product yet, but 3M Comapny seems best for tapes. High technology, hundreds of different pressure sensitive tapes and informed salesmen. 3M's Y-9057 Tedlar tape is very good, supposed to last 15 years, and quite expensive. Scotchrap tape is cheaper, a 10 mil black PVC tape used for wrapping pipes. This is what we used on the Aluminum Triacon dome. 3M also has double-stick tape, and a tape that you apply, then lift off, leaving a sticky snail track. Arno adhesives makes an aluminum tape that might work on aluminum domes.

The big disadvantage of a pressure sensitive tape is that it does not stick to itself well, as at vertexes. The tape is coated with a release agent so it peels off the roll easily. However, pipe wrapping tape is made to stick to itself, and sticks well to aluminum but not to vinyl windows.

### Our Attempts at Sealing Plywood Dome Seams:

*1. We used Vulkem 230 one-part polyurethane caulk. Our seams were not of a standard width, varied from 1/16" to 3/8" in width. We didn't prime or clean plywood edges. Before nailing on plywood, we stapled strips of polyethelene to struts. We used this caulk both at plywood seams, and to seal the vinyl windows and batts(it worked well on the vinyl). It worked more or less for a year, except in the more poorly-built domes. During the first summer, it cracked in most of the narrow joints, pulling away from the plywood edges. When this happened we tried several remedies:*

*2. Permalume mastic and BC Chrome elastomeric liquid foil. A bummer, same experience reported from Libre.*

*3. Acryl-R 5505 narrow joint seam sealer, then vinyl tape applied over that. We cleaned the joints with a rag, but didn't plane them down, or route out. It works fairly well, will probably last for a year or two.*

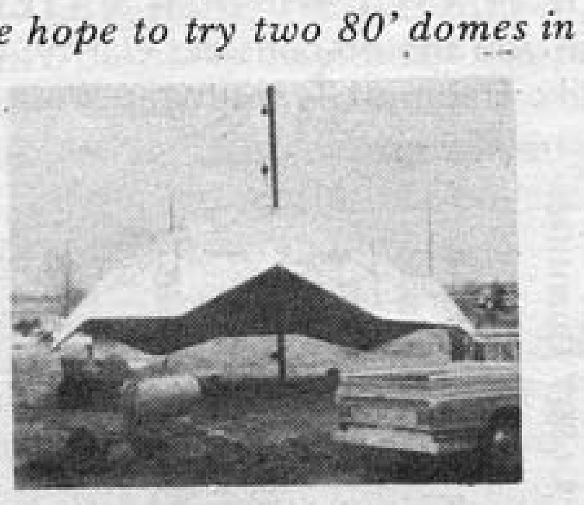
*4. Imron, a DuPont polyurethane caulk which looks better than the Vulkem.*

*5. Elastron No. 870, which is very hard to apply neatly, but appears to be working well. This is a two-part black rubber sealant, and could probably be done neatly with masking tape and care. It cost us about $80 for a 24' dome with about 750 lineal feet of seams.*

### Econo

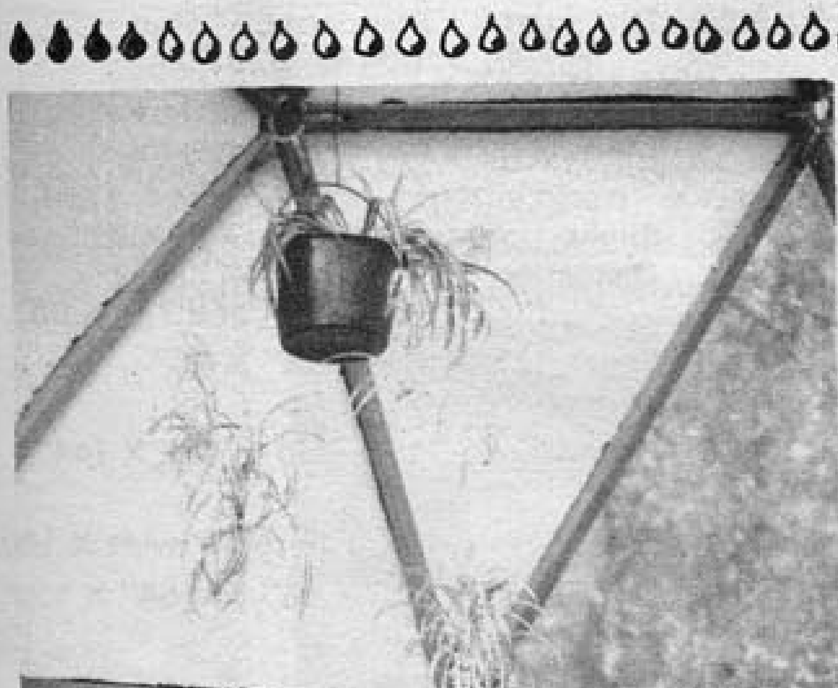
*We put up this 40' dome of steel in 3 days in a 20-25 mph wind with no trouble. We are not having trouble with sealants. We are using a redundant system of butyl rubber caulk and 3M425 aluminum tape. We are working on a cheaper sealant that consists of a strip of galvanized steel with tabs spot welded and the tabs put between the struts and bolts then tightened. It seems to work fine but it hasn't been on a building long enough to tell yet.*

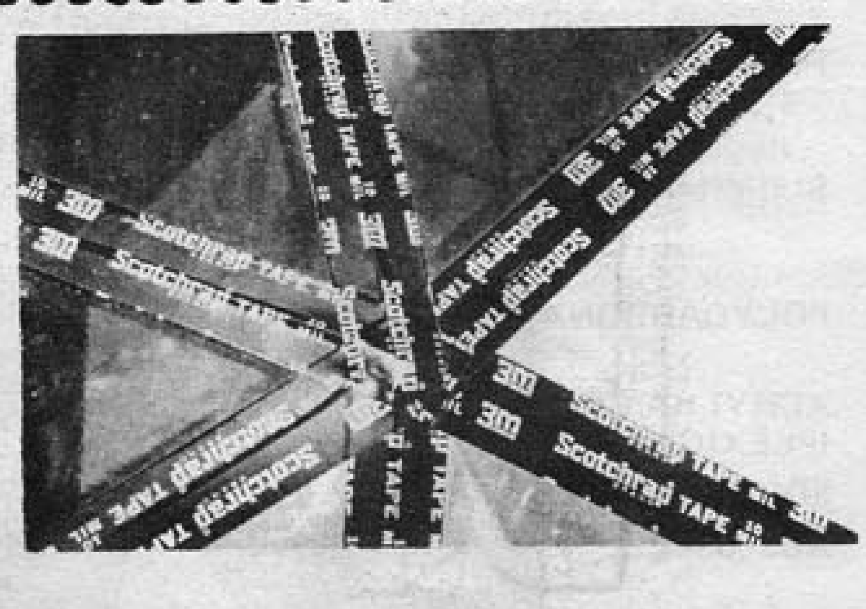
*We have put up 9 domes and we hope to try two 80' domes in mid March beside the one photographed.*

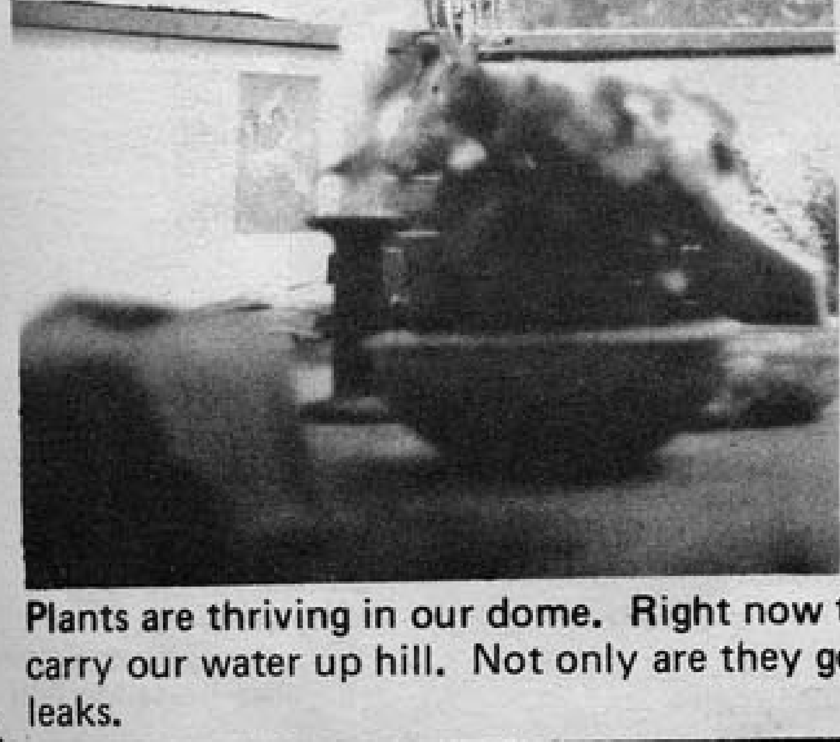


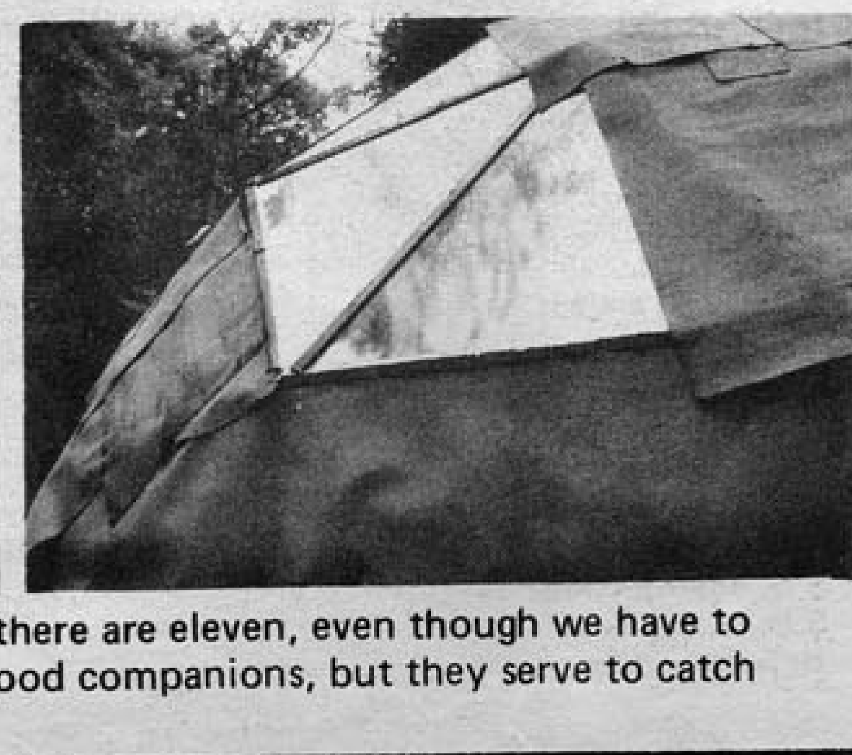
*Dale French*

*Econo Building Dept. D*
*1522 N. Pennsylvania*
*Shawnee, Oklahoma 74801*







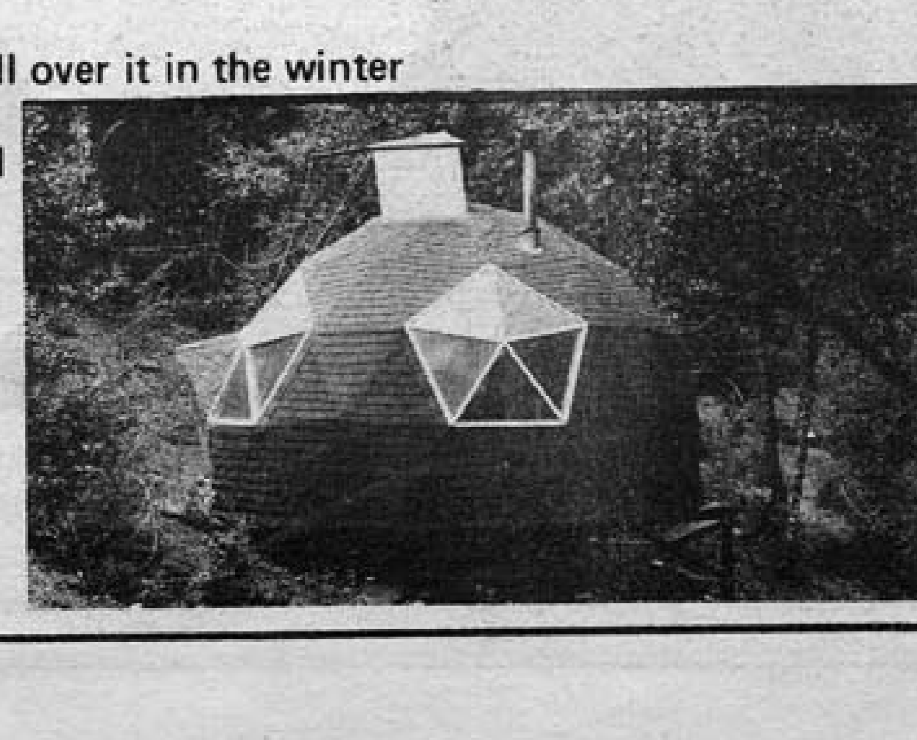
Plants are thriving in our dome. Right now there are eleven, even though we have to carry our water up hill. Not only are they good companions, but they serve to catch leaks.

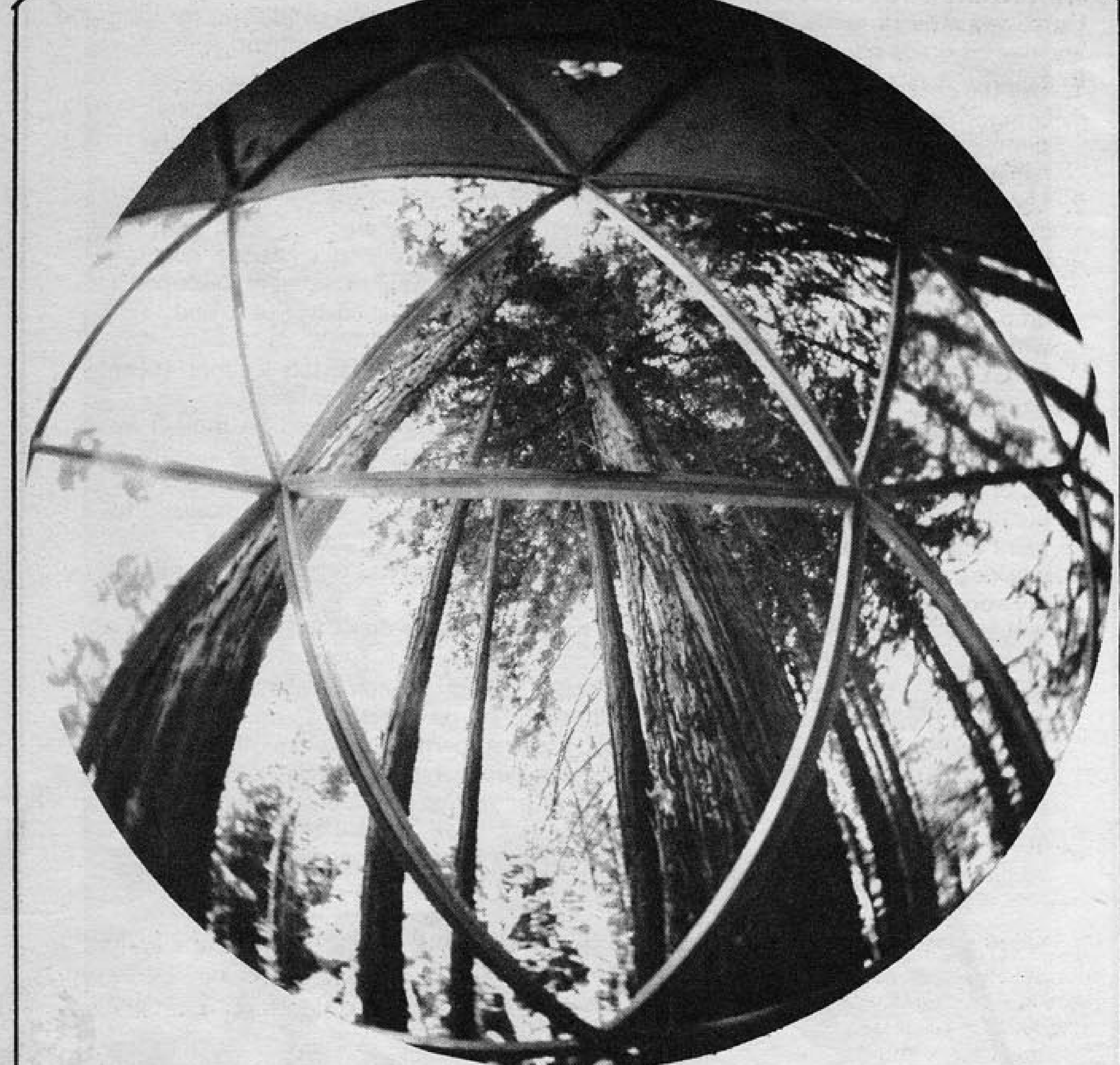
## WEATHERPROOFING PLYWOOD

Untreated exterior grade plywood will not hold up under sun/rain conditions for long, and and marine grade plywood is very expensive. There are several alternatives:

1. Use the cheapest grade of plywood *with exterior glue,* and cover with wood or composition shingles. Tar paper is used underneath the shingles, two layers for safety. Shingles are flexible and bend over seams. You can also use roll roofing paper, shingled as metal in sheet metal domes.
2. Use exterior grade plywood, coated with one of the following:
   a) fiberglass: Dyna Domes sprays glass on triangles before erection. First resin is sprayed on the surface, then chopped fiber is sprayed on with a chopper gun, then more resin, then rolled smooth with a roller. Seams are treated as described on p. 90, then the whole dome is sprayed with either a final coat of resin and white pigment, or acrylic paint.
   b) GE Silicone Weather Topping: sounds very good. See Materials section. It can be rolled on. We haven't tried it yet.
   c) Elastron (different stuff than used for seams): also sounds good. Although we've used it at seams, we haven't tried it over an entire dome.
3. U. S. Plywood's "Duraply" has a lifetime(of building) guarantee not to delaminate, etc. It is impregnated with resin and surfaced with a waterproof paper designed for paint application and waterproofing. We've used it for seven domes and it is working satisfactorily so far. It's about twice as expensive as regular exterior grade plywood.
4. Weyerhaus' silicone coated plywood: a new product, we don't yet have information on it.
5. Bob McElroy has built two pod domes in Big Sur using rough sawn exterior grade redwood plywood, which seems to be working. I'd be reluctant to use redwood, as there are hardly any redwood trees left. However, perhaps there are other types of exterior plywood. This gives the dome a rustic appearance, especially if rough-sawn **although the lack of a smooth surface can cause sealing problems at seams.**

Our dome's a soggy mess.
Why don't we get a big plastic sock to pull over it in the winter
It's leaking all over Mako's loft
It swelled up now and doesn't leak so bad
Man the only dry place is Glen's bed
Durkees got the right idea—shingles.
Do it the old way. It works.



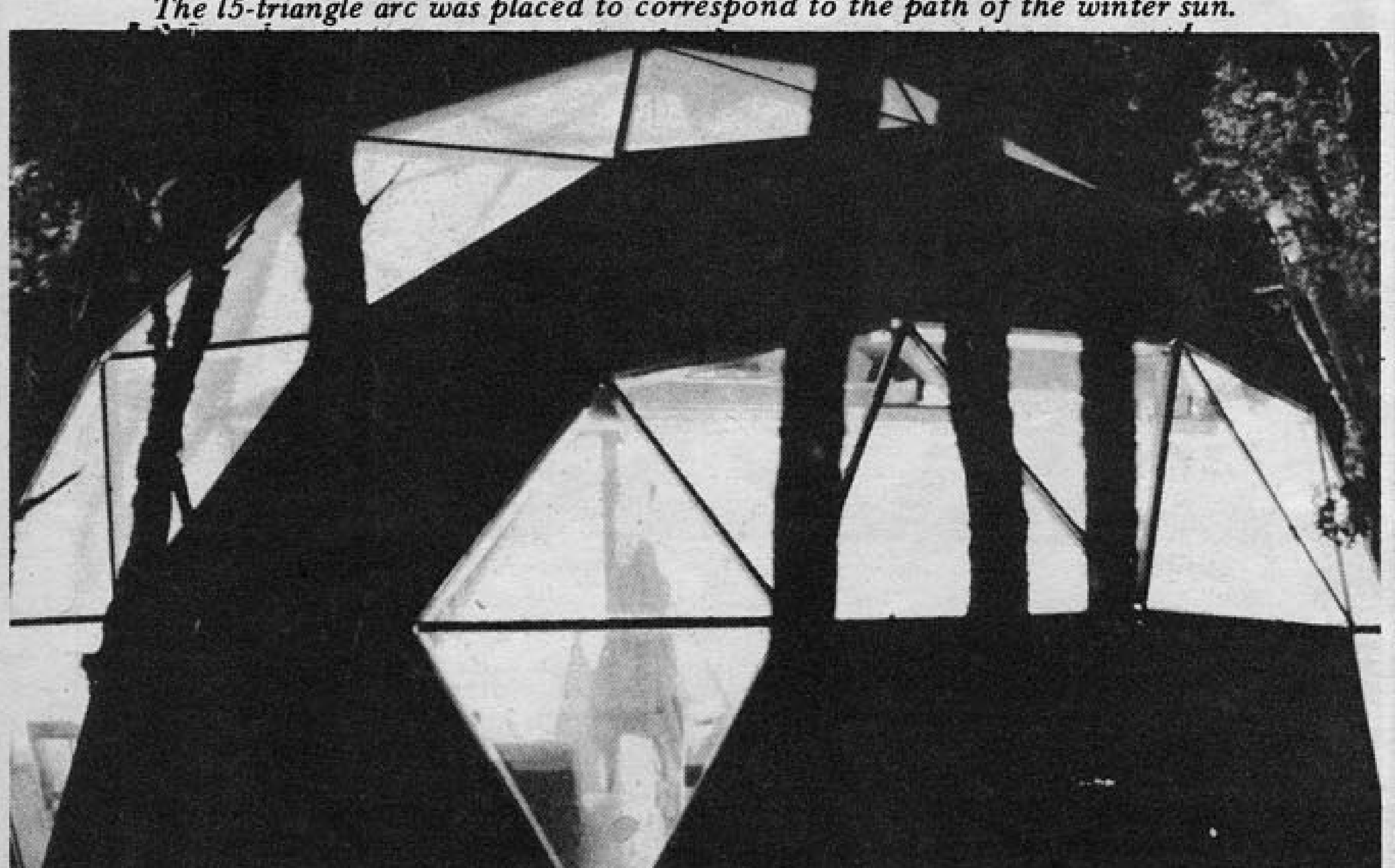


# WINDOWS

Windows are the eyes of a dome. They're important in placement, what you see through them, in light brought inside, and optical clarity (or lack of it). Windows, together with the opaque skin, make a pattern in the dome, and it is in window patterns that our domes are perhaps most unique.

With all our windows we followed the domes' geometry, as opposed to inserting something like sliding rectangular aluminum windows. We used flexible vinyl, which was about 6 cents per sq ft, came in 54" wide rolls, and had an ultra-violet resistant. With the first few domes, the patterns were rather conservative. Then Bob, Alan, Jonathan—students—building their dome in a grove of trees on a hilltop, did the first arc:

*The 15-triangle arc was placed to correspond to the path of the winter sun.*



These large window patterns were based upon a mild climate, cheap material, and a flexible window material. In a more severe climate than California, one would not want such large window areas, primarily due to heat loss in winter, heat build-up in summer (heat passes right through single thickness windows).

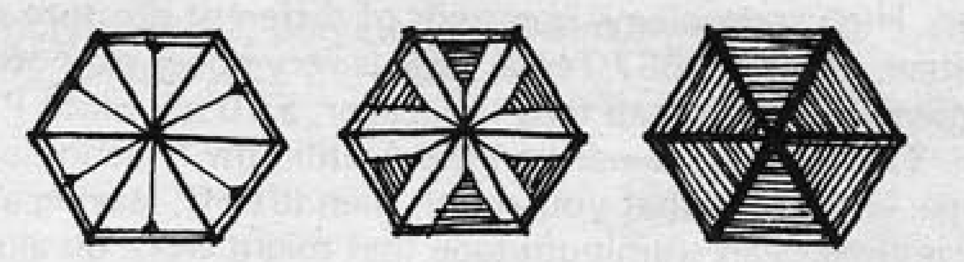
## USEFUL INFORMATION ON WINDOWS

—a small amount of light coming in at the top will illuminate the dome surprisingly well, especially if the interior is white. Light cascades down the interior surfaces.

—windows generally cause leakage problems if not properly designed and installed. Windows at the top of the dome are more of a problem than those on the side, as water does not drain as fast off the more horizontal surfaces. Rigid or semi-rigid windows move a great deal in expansion-contraction, causing leaks in many cases. Window design should allow for this. This is not a problem with *flexible* window material.

—optical clarity is highly desirable. The flexible vinyl we used has an ultra-violet resistant in it that causes distortion—sort of a wavy effect. You're not so aware of this until you see a perfectly clear window and realize how much more beautiful it is to see trees and stars clearly. Glass is clear, as are certain of the plastics such as plexiglas, Lexan and butyrate. However, glass is dangerous to have overhead (unless it is safety glass, which is expensive). Some of the plastics tend to scratch easily and may yellow over the years. The ideal material would be flexible, resistant to ultra-violet, and optically clear.

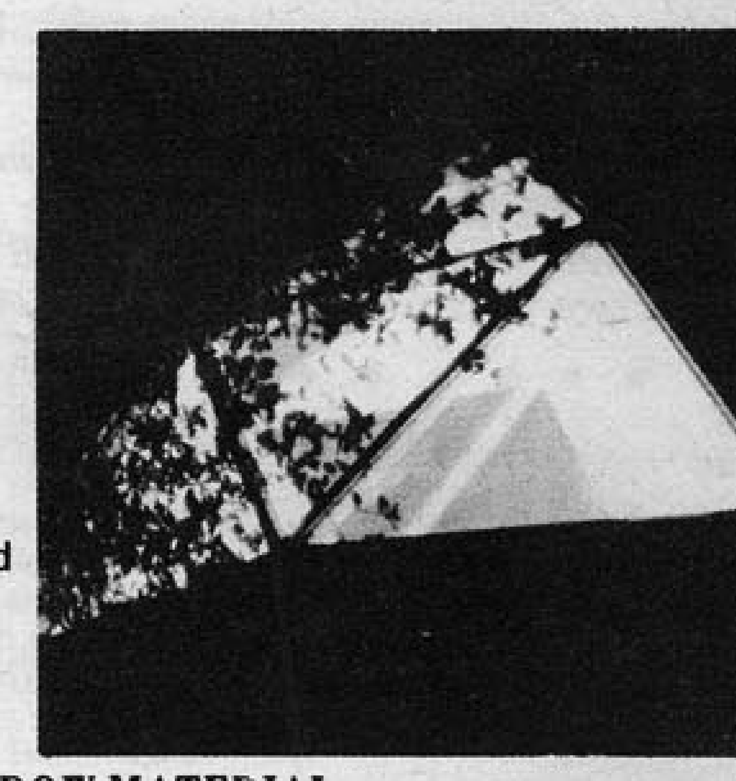
—large window areas must not face the summer sun, or must be shaded to prevent high and unpleasant heat build-up in summer. One of our domes got so hot last summer that candles melted. Windows facing south and west will get summer heat. Painters' studios generally have north light, as sunlight does not come from the north. An ideal situation is to have deciduous trees—which drop their leaves in winter—on the south and west, so there is winter sun, and summer shade. Neill Smith is growing a vine over his transparent dome. The Expo dome has shades that pull into the center of the hexagons:



—not only is there heat gain in summer, there is heat loss in winter through windows. Clear areas can be insulated by using a triple layer of window material(two unsealed layers cause condensation in-between) or by putting in insulation(such as sheets of rigid foam) during extreme heat or cold, or by using aluminized or tinted window material. Fuller told us that the Dymaxion House had two layers of plexiglass with an 1/8" air space in-between, sealed around edges.

—you can study window patterns with models. Make a cardboard model, use plastic wrap for windows, take it to the site and hold it overhead.

—if you build a type dome where the frame goes up before skin is applied, sleep underneath, study the strut pattern, watch the sun, moonrise, stars. Try to figure the path of summer sun, which is higher than winter sun(with careful planning it's possible to have windows that admit winter sun, but are too low to admit summer sun—a shade is probably necessary here. *The Owner Built Home* has some good information on this - see p. 119. You may want to have windows facing east near the bed, so you're facing in the direction of the earth's spin, and see new stars appear on the horizon.



Away from city lights, if you sleep out, or if there's a window above your bed, you'll watch stars, moonrise. You'll get accustomed to the speed of the earth's spin as different stars appear on the horizon.

## COMPARATIVE CHART OF PLASTIC WINDOW MATERIAL

In selecting window material you should consider clarity, weatherability, burnability, price, and sizes available, Mike Rabin of Transilwrap West Corp, 1579 Custer Ave., S. F. has prepared the following chart:

| | Price per sq ft In 300' Quantities | Weatherability | Cold in Pack | Windy Areas | Sunny Areas | Shady Areas | Flame Spread | Clarity | Standard Sizes |
|---|---|---|---|---|---|---|---|---|---|
| FLEXIBLE VINYL .020 | $ .12 | F | F | P | P[3] | F | S.E. | Distorted | Standard 54" Roll .004 to .020 |
| FLEXIBLE VINYL P.P. .040 | .30 | E | F | P | E | E | S.E. | Optically Clear | Sheets as used in rear convertible windows 21" X 5l" and 27" X 62" |
| BUTYRATE .060 | .41 | E | E | E[1] | E | E | S.B. | Slight Distortion | .060-.125: 48" X 72" .125 Up: 48" X 72", 48" X 96" and 72" X 96" |
| POLYCARBONATE .093 | 1.18 | E | E | E[1] | E | E | S.E. | Slight Distortion | .093: 48" X 96" 60" X 96" |
| ACRYLIC .125 (PLEXIGLAS) | .90 | E | F | E | E | E | S.B. | Optically Clear | .125: Up to 96" X 144" |
| POLYETHYLENE .006 | .015 | P | E | P | P | F | B | Hazy | Rolls up to 40' wide X 100' |
| ABS .060 | .34 | P | E | F | P[2] | F | S.B. | Opaque as of now | 48" X 96" and 54" X 120" |
| MYLAR (W) | DISCONTINUED | | | | | | | | |
| MYLAR-MIRRORIZED ONE-HALF DENSITY | .09 | | | | | | | | |
| OUTSIDE | | P | E | P[1] | P | F | S.B. | One way Good | Rolls 54" wide |
| INSIDE | | E | E | E | E | E | S.B. | One way Good | Rolls 54" wide |

All figures are averages.

E=Excellent - 5 years and up
F=Fair - 2 to 4 years
P=Poor - 6 months to 2 years
1=In small panes
2=Unless it has Korad Cap, in which case it would be E
3=Unless U.V.I. Stabilized, in which case it would be F
S.E. =Self-Extinguishing
S.B. =Slow Burning
B=Burns

| *Generic Term* | *Trade Names* |
|---|---|
| Butyrate | Uvex |
| Acrylic | Plexiglas-Acrylite-Polyglass |
| Polycarbonate | Lexan-Rowland(Make sure to specify U.V.I. Stabilized) |
| Flexible Vinyl | Vinylite |
| Polyethylene | Visqueen-Gerpac-Coverall Royalite-Bolta-Marbon |

## VINYL

We used flexible 15 and 20 mil vinyl because it was cheap and easy to apply. We stapled the vinyl over the plywood *around* the window area, then nailed batts over and caulked with Vulkem polyurethane sealant(which does not have a solvent in it and therefore does not eat away the vinyl). This is a funky way to put on windows. The easiest way to apply flexible vinyl is in long arcs, where there are no(or few) seams. The vinyl is somewhat elastic and can be stretched tightly.

We have heard that 2 mil metallized vinyl is being manufactured somewhere on the east coast. Aluminized mylar has been available for some time, but does not take outdoor exposure well. The metal surface of mylar on the Hollywood Hills dome (see p. 99)wore off in three months. The metal surface helps in reflecting summer heat off, keeping winter heat in. It's possible to put an aluminized membrane inside plexiglass, Lexan, or glass. Transilwrap has a new very lightweight aluminized mylar.

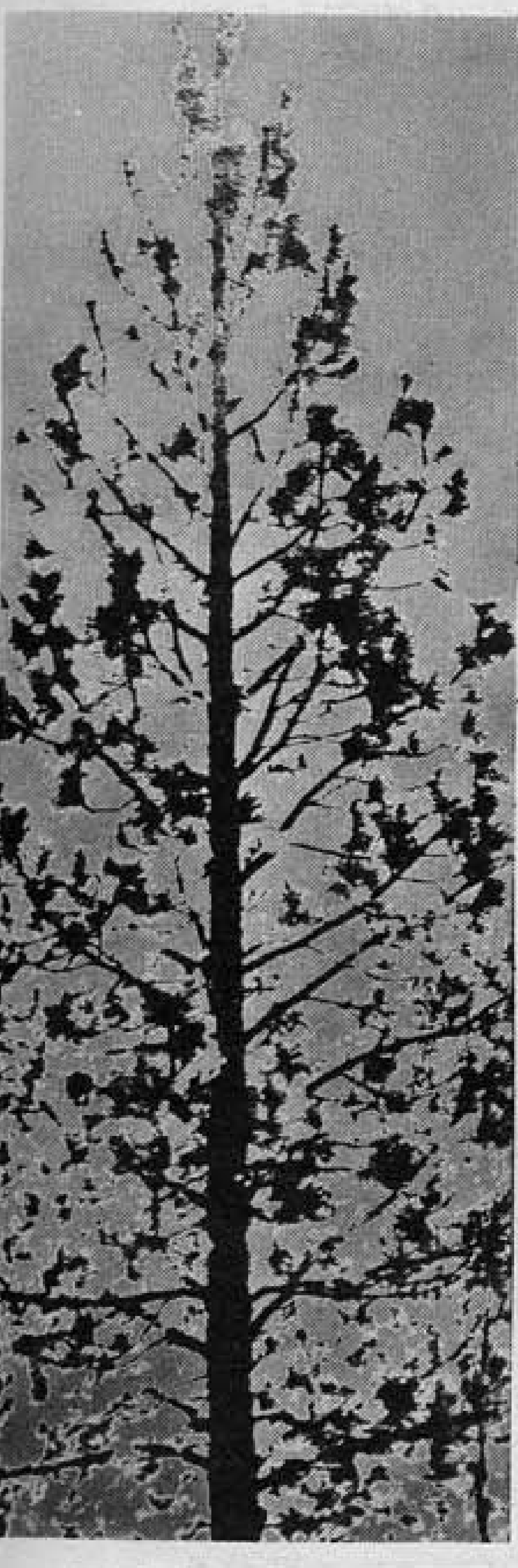
## BUTYRATE

Kodak calls their product Uvex: an outdoor formulation of cellulose acetate butyrate, commonly used for gas station signs. It can be solvent cemented to produce a bond as strong as the material. We haven't used any, but I believe Alan Schmidt has used some at Ananda. See Materials, p. 86 for information.

## POLYCARBONATE (LEXAN)

Super tough clear plastic material, called Lexan by GE, Monel by Mobay. It is guaranteed not to break. Like other clear plastics it scratches easily; to avoid scratches, get the material with masking on both sides. GE has published the following information on the material. Ask your local GE outlet, or write GE, One Plastics Ave., Pittsfield, Mass: *Lexan Fabrication Data / Lexan Sheet Processing Tips / Lexan Design Tips / Lexan 500* (stronger than metal) */ Practical Design Characteristics of Polycarbonates / Lexan Film and Sheet Thermoforming / Lexan Chemical Resistance Data.*

Extracted from GE information sheets:



Hot bending of formed parts or specific sections of sheet is done easily with polycarbonate, as is bending of entire sheets into relatively simple forms such as face shields. Stock temperatures of 300-325 F are satisfactory. Going higher than 325 F will result in bubbling unless the part or stock is pre-dried.

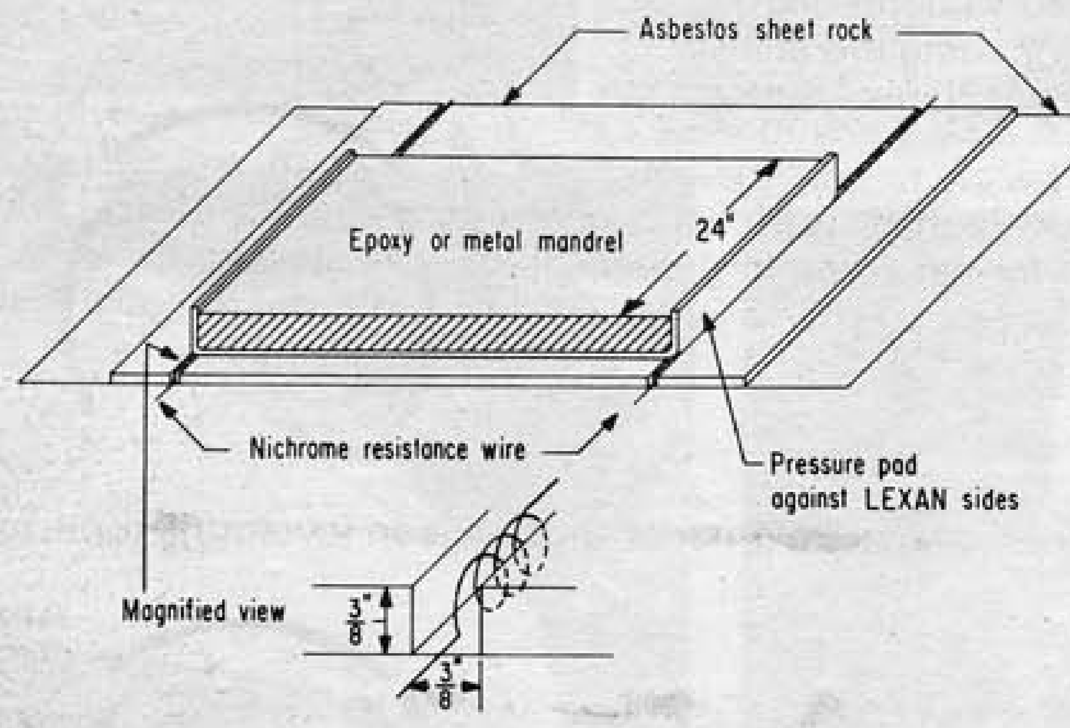
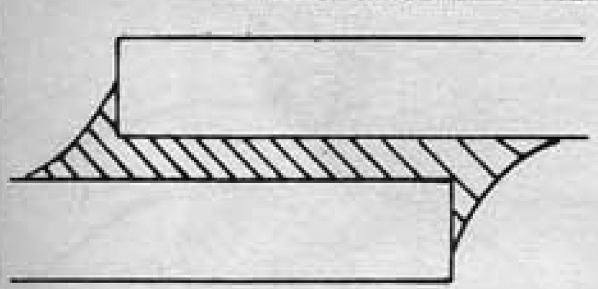



**Fig. 27. Hot bending of LEXAN sheet.**

As shown in Figure 27, one way to apply heat is to use a nichrome resistance wire embedded or nested in asbestos sheet rock. Use of a Variac will make temperature control simple and uniform. Varying the width of the slot for the resistance wire, plus use of appropriate jigs and clamps, will permit control of the radius and width of the bed area to close tolerances.

In forming simple shapes like a face shield, a precut blank is clamped in an air-circulating oven until the stock temperature reaches 300-325 F, at which point it can be handled like acrylic. With rapid transfer to a flannel-covered mandrel, the required shape can be made.



SIMPLE LAP

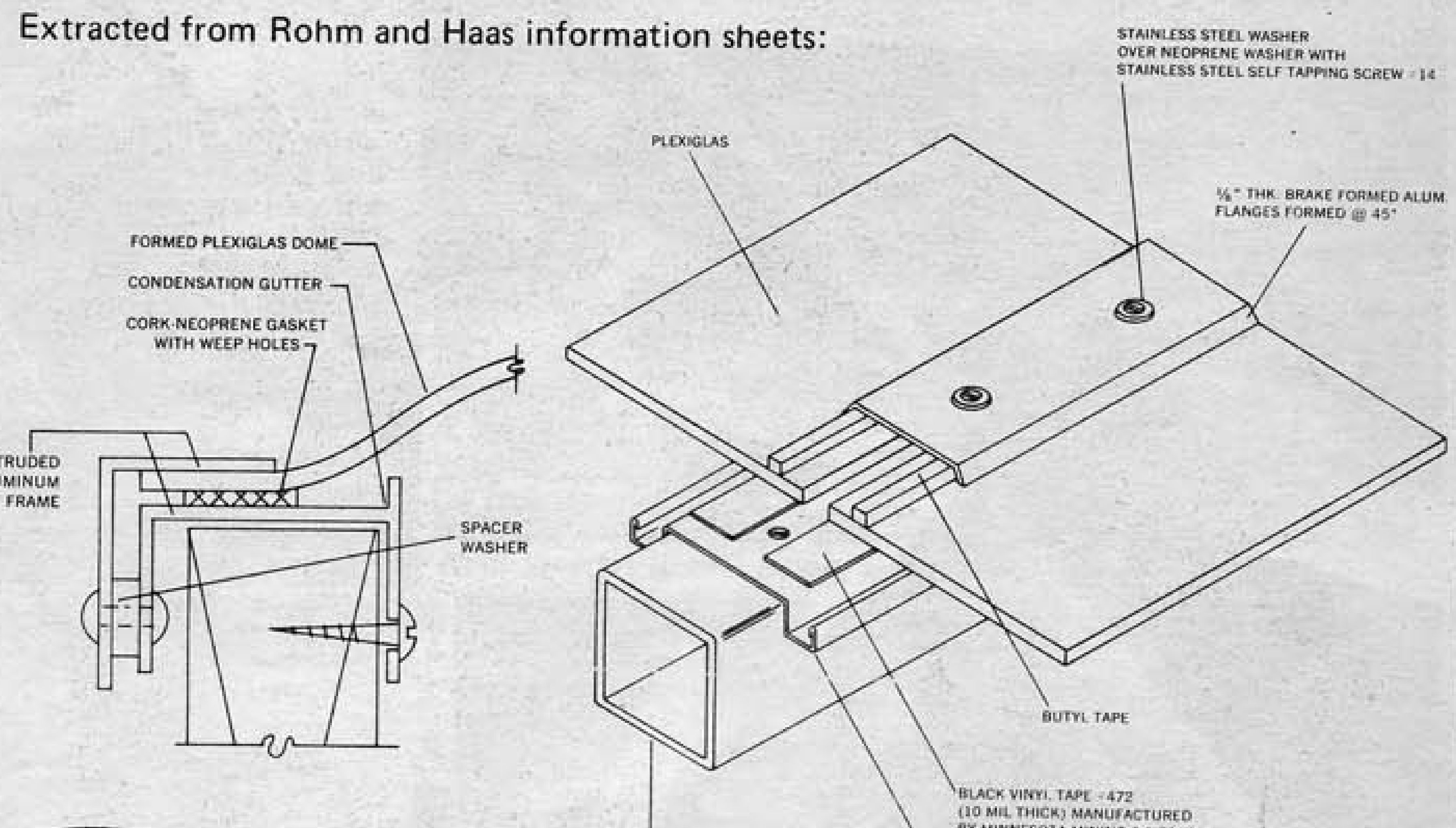
Joint design, too often overlooked, should be considered in the early design stages of the LEXAN part whether solvent cementing or adhesive bonding is used. The joint design should create a bonding area carrying the load equally, with the major stresses in shear or tension to minimize cleavage and peel stresses.

Coming up through the trap door on a moonlit night. Underneath the dome it's dark, I fumble for the door, push it open: a ring of five moonlit diamonds framing a pentagon star, it's dazzling! Inside, before we light the lanterns, we watch the play of moonlight through leaves through diamond windows on the floor, on us.

## PLEXIGLAS

Rohm and Haas is the big manufacturer although I'm sure by now the Japanese are making it cheaper. Plexiglas is tough, clear, easily cemented and dependable. The Expo dome at Montreal had *solar control* plexiglas, tinted in five shades—darkest at top—for control of heating. A great deal of good information, including color brochures is available from Rohm and Haas, Independence Mall West, Philadelphia, Pa. 19105: *Plexiglas in Architecture(PL-688b) / Innovations in Building Facings with Plexiglas (PL-730) / Domes and Arches of Plexiglas(PL-659) / Plexiglas Solar Control Series(PL-777) (PL-777).*

Extracted from Rohm and Haas information sheets:




### Plastics cutter

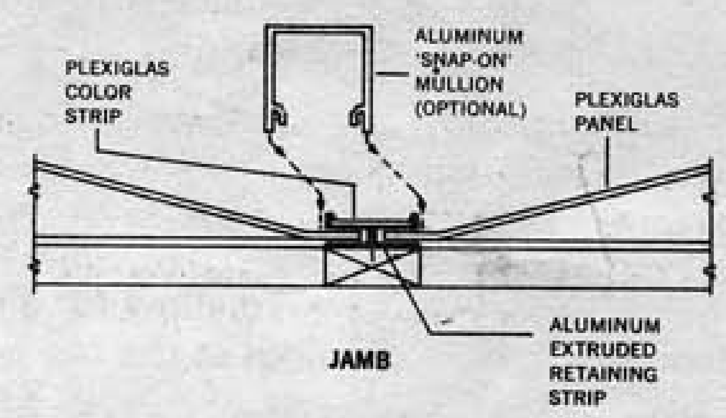
Got a project going that uses acrylic sheets? Here's a scriber for accurate, fast-breaking, clean cuts with a minimum of passes. Red Devil, Inc., 2400 Vauxhall Rd., Union, N.J. 07083, makes it to sell for under $2.

catalog on skylights, extrusions from O'Keeffe's Inc.
75 Williams Ave.
San Francisco, Ca. 94124

Plexiglas is virtually unaffected by most household chemicals used for cleaning surfaces, such as light and heavy duty detergents. However, the material is affected by paint thinners, turpentine and similar solvents.

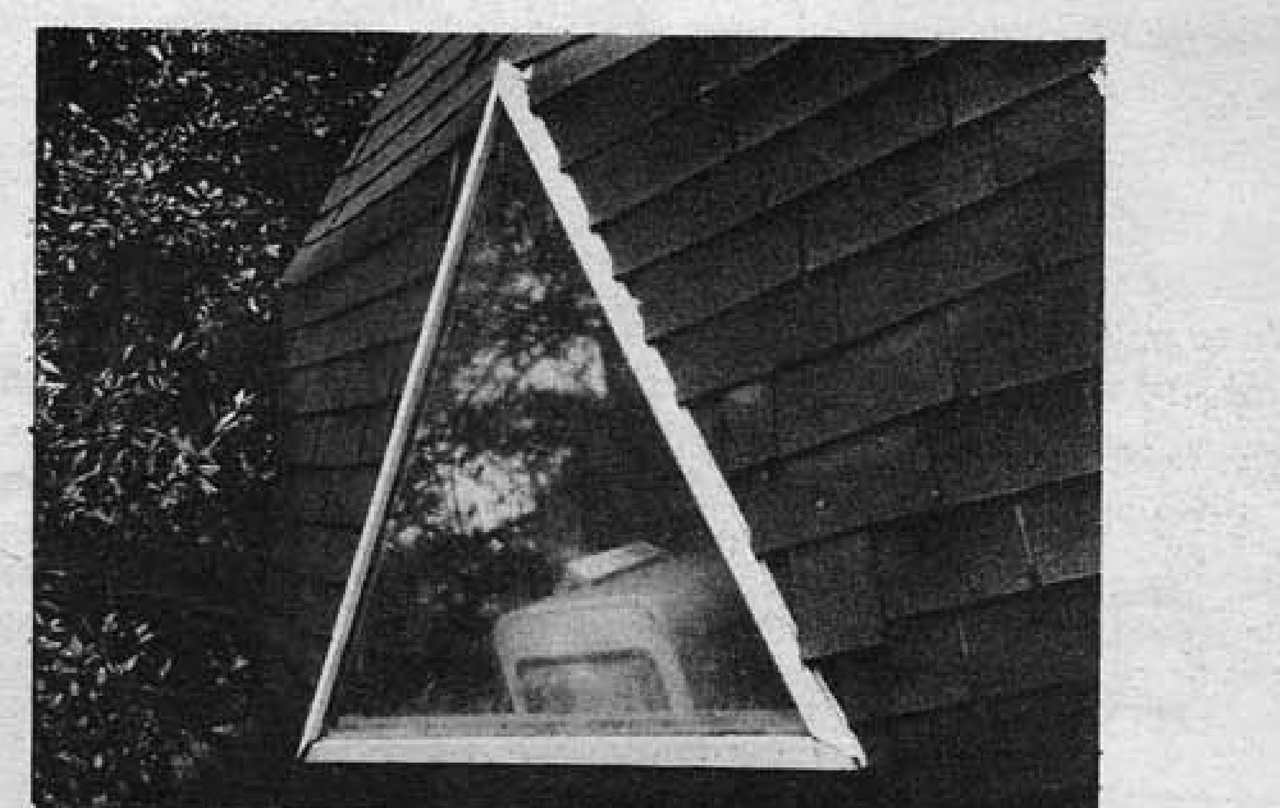
**Specifying Sealant Systems for Glazing Large Plexiglas Lights**

1. Butyl tape and neoprene filler blocks
2. Silicone or polysulfide sealants and filler tapes




## FIBERGLASS

I made translucent fiberglass windows for my dome in Big Sur of 1½ oz mat and resin. I used formica to lay it on, waxed the surface, layed down the triangle of mat(cut larger than the window—to be trimmed later), rolled on resin with a paint roller. The best roller to use with resin is the type with a rug-like roller, not the fleecy type. I think it cost about 15¢ per sq ft. I wore a good two cartridge mask for fumes, but after 30 windows, I was tired of the process—sticky, time consuming, and fumes get through the mask.



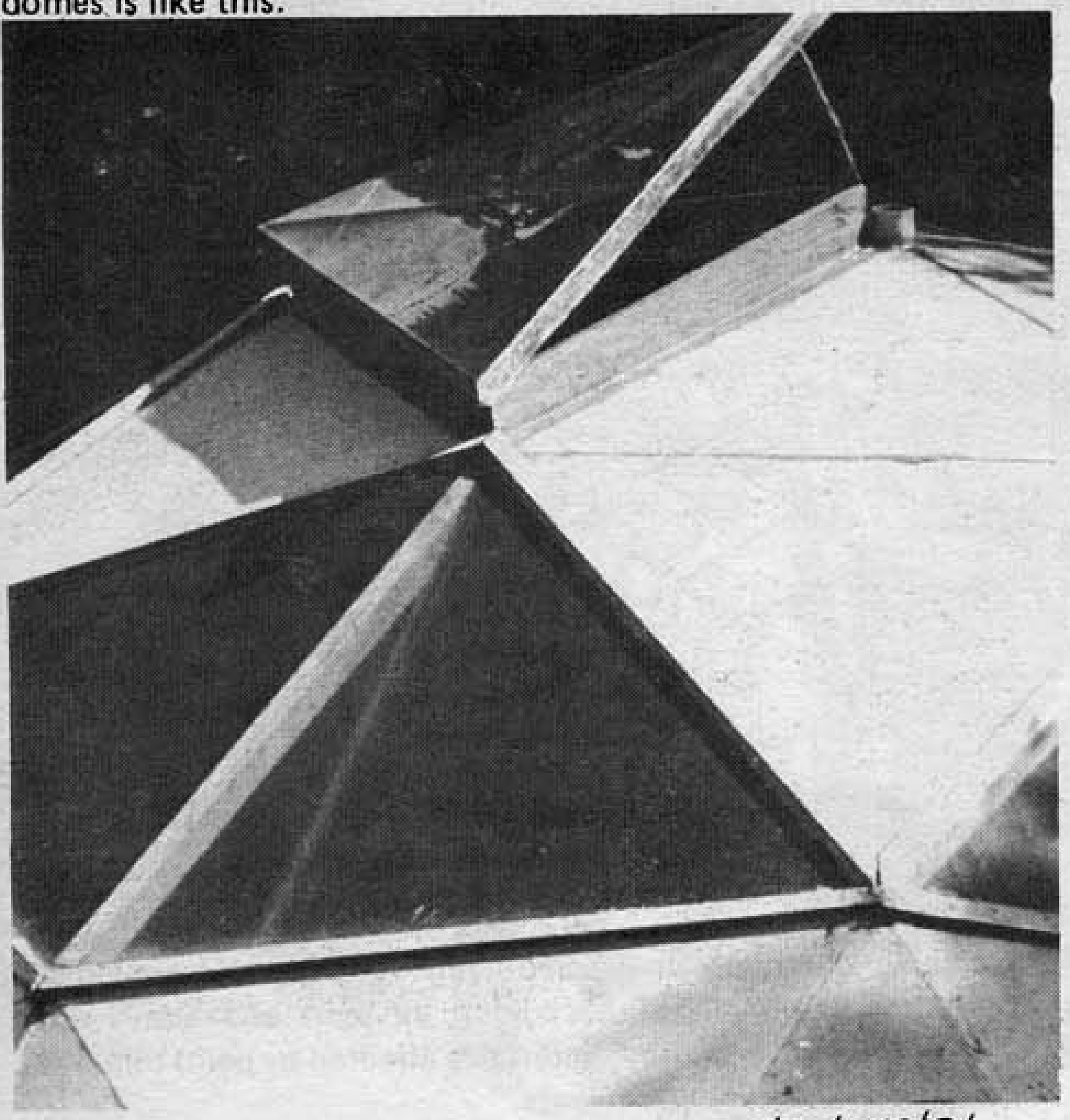
*When his new tea-room and garden were completed at Sakai, he [Rikyu, a famous Japanese tea-master] invited a few of his friends to a tea ceremony for the house-warming. Knowing the greatness of Rikyu, the guests naturally expected to find some ingenious design for his garden which would make the best use of the sea, the house being on the slope of a hill. But when they arrived, they were amazed to find that a number of large evergreen trees had been planted on the side of the garden, evidently to obstruct the view of the sea. They were at a loss to understand the meaning of this. Later when the time came for the guests to enter the tea room, they proceeded one-by-one over the stepping stones in the garden to the stone water basin to rinse their mouths and wash their hands, a gesture of symbolic cleansings, physically and mentally, before entering the tea-room. Then it was found that when a guest stooped to scoop out a dipperful of water, from the water basin, only in that humble posture was he suddenly able to get a glimpse of the shimmering sea in the distance by way of an opening in the trees, thus making him realize the relationship between the dipperful of water in his hand and the great ocean beyond, and also enabling him to recognize his own position in the universe; he was thus brought into a correct relationship with the infinite. . . .*

*From* Japanese House & Garden
*by Dr. Jiro Harada*

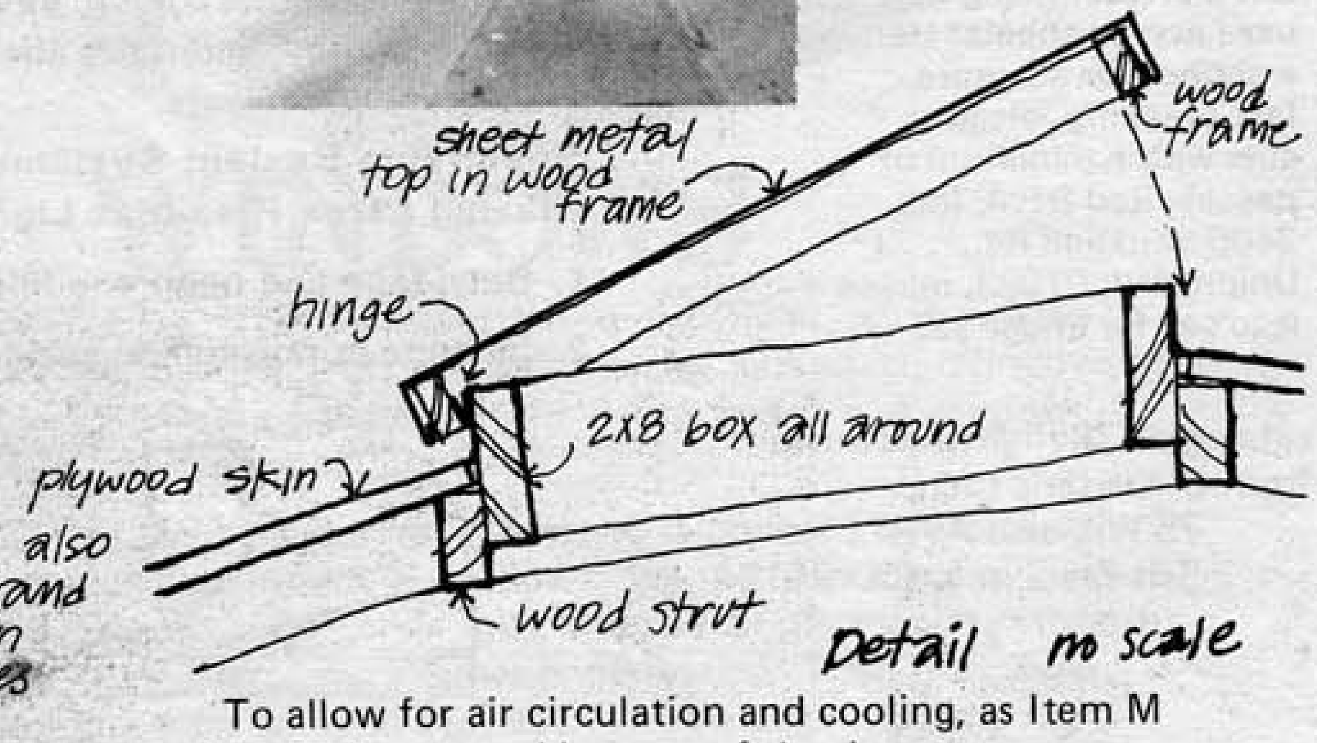
# VENTS

The warmer the weather, the more vent area is needed to keep temperatures in the dome tolerable. It also helps to paint the dome a light color to reflect sun rays, and to shade windows that get south and west sunlight. See also Windows, pp. 80-81.

**Simple vent**
Ventilation at the top can be achieved by opening entire triangles. Simplest for plywood domes is like this:



*As there is a loft in the dome, I can climb up and prop the vent open with a stick. Usually the vent is open; in hot weather it's all the way open.*



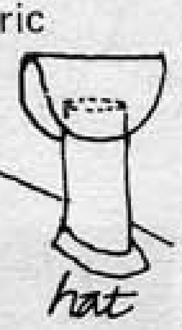

To allow for air circulation and cooling, as Item M shows, it's desirable to have openings at the top and bottom of the dome.

**Base vents and eaves**
Lower vents can be anywhere, even in the floor. If on the side of the dome, an eave can be built to shed rain water. Lower vents should be screened. Floor vents can have a wind scoop underneath to increase air flow.

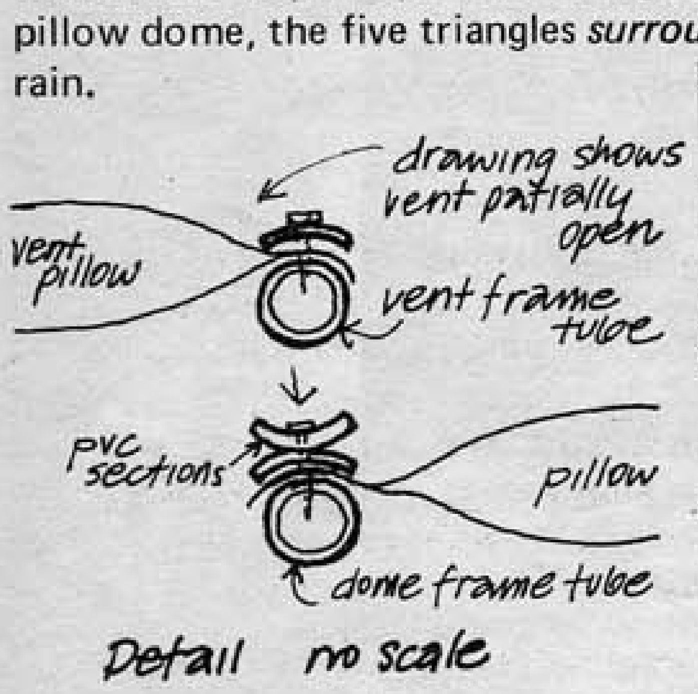
**Tent Vents**
Flexible membranes can be vented with zippers. Check out a camping store to see how tents are vented. Zippers can't take severe strain; rounded corner openings are less likely to tear. See also Tent Domes, pp. 48-49.

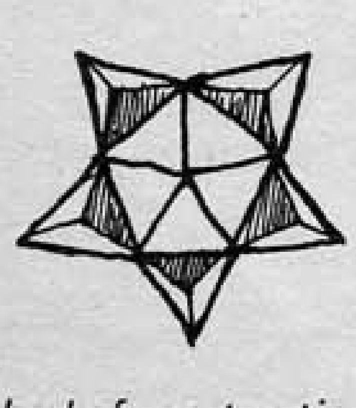
**Umbrella vents**
Triangles, pentagons or hexagons can be raised above the surface of the dome and the space between used for ventilation, as in Item M. The entire umbrella covering could be jacked up and down, or have small flaps around perimeter.

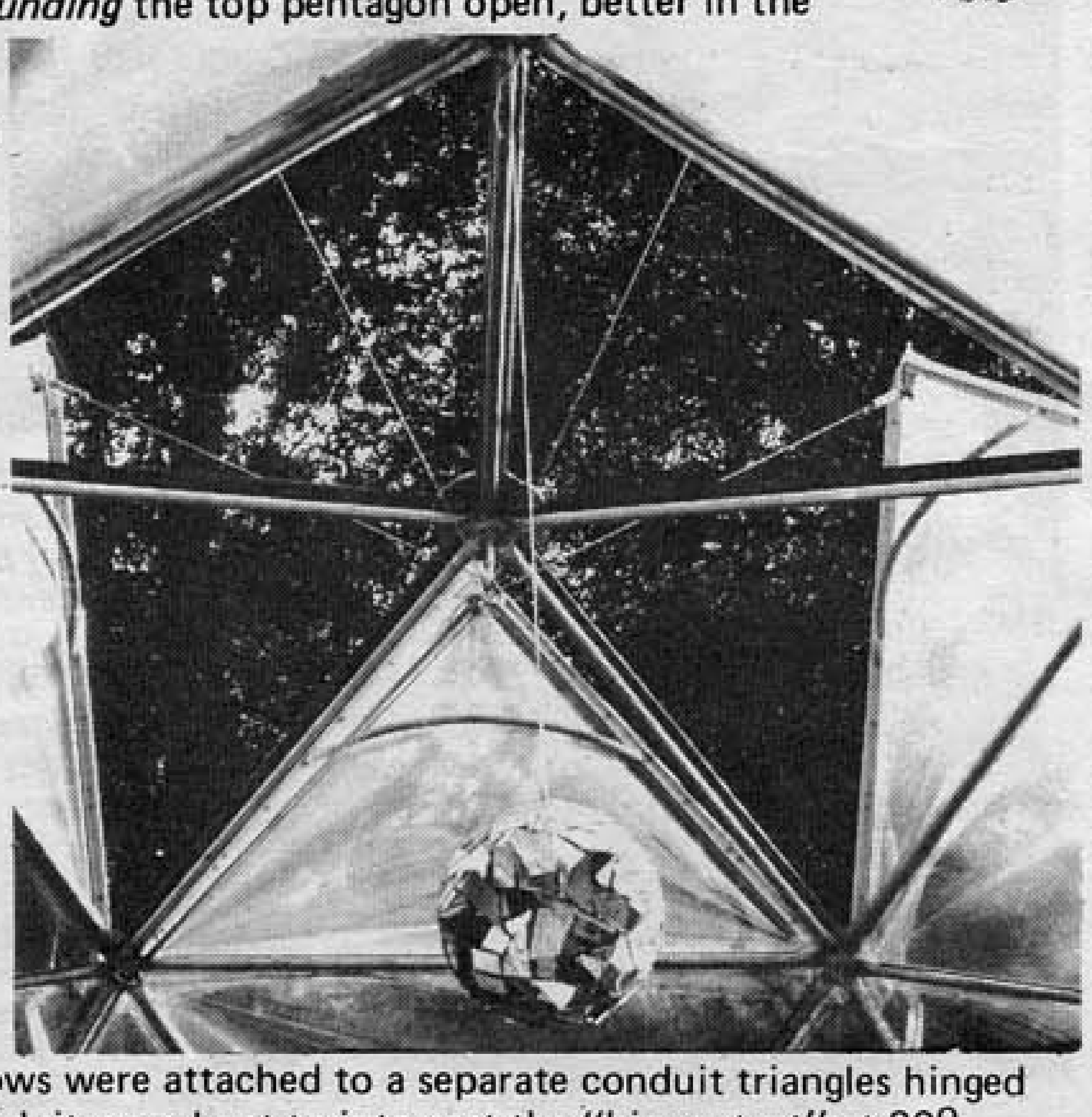
**Hats**
A small vent can be made by using short 6" stovepipes (with dampers if you want control) topped by hats. Commercial rotating vents can also be used. You can also use electric blowers.




**Pillow dome vent**
Jay built this vent system for the tube frame pillow dome, using springs activated with a cord to pull open the triangles of the topmost pentagon. In the next pillow dome, the five triangles *surrounding* the top pentagon open, better in the rain.





*Method of construction:* the pillows were attached to a separate conduit triangles hinged to the frame. The ends of the conduit were bent to intersect the "hinge-strut" at 90°. The two pieces of conduit that make up the vent and the two corresponding pieces of the open triangle were bent in a slight arc to counter-act the pull of the inflated pillows.

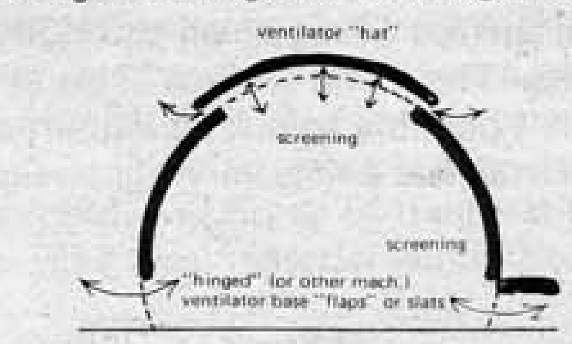
Two pieces of split PVC pipe were screwed to the edges of the open triangle—the upper pipe half catches the opening frame.

# FULLER ITEM M

A partial sphere seems ideal for a natural cooling and circulation system.

**The following information was extracted from Item "M", Boston Blue Print Data Archive by R. Buckminster Fuller:**

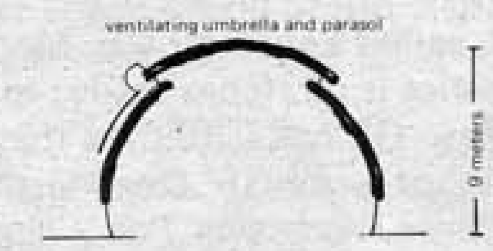
*Be sure* to design your building with *large* ventilating and reflecting areas *both* top and bottom with screens, etc.




If you use a six-meter radius and a 5/8 sphere, your structure will look about as below—and, as you have learned, the seemingly empty space is full of *invisible energy operations* in your favor. Trees may also live inside, to mutual advantage of man and tree.

Mobile Shading Device in summer—reflects sun outward; in the winter—reflects sun inward.

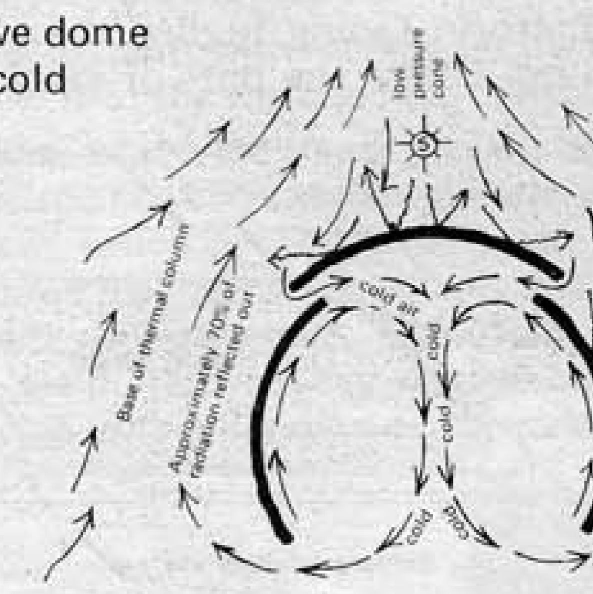
Living area or controlled garden area—approx. 110 square meters.




This space should be treated as a controllable outdoor garden, with the concept of a *"house" as a "fortress"* completely dismissed.

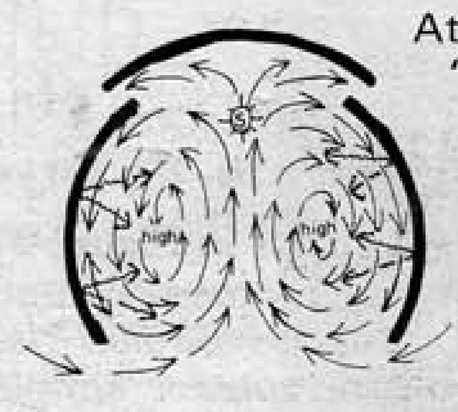
Think of the structure as the masts and spars of a sailing ship were thought of, i.e., as a mobile system of overhead "vantage" (as with shipyard "cranes") for mounting any kind of local "circuses" of atmospheric and energetic events. Send skins aloft like sails on a ship.

low pressure cone above dome draws down a central cold air core countering major rising thermal spiral column




Atmospheric movement when sun, as heating element is *outside* structure, i.e. on the reflective *convex* side of system which diffuses energy outwardly.

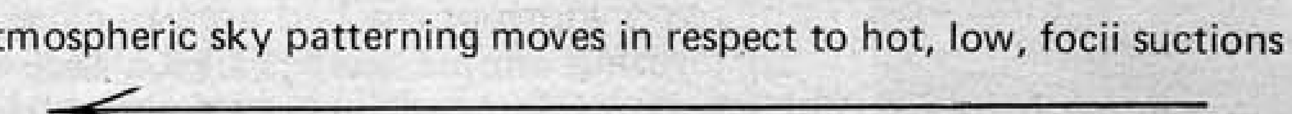
Interior motion is an involuting torus (doughnut shape)



Atmospheric motion when little local "sun" i.e. heating and lighting elements are near top *inside* of system, i.e. on *concave* side of system which concentrates energy inwardly.

Interior motion is an evoluting torus (doughnut shape)

Total atmospheric sky patterning moves in respect to hot, low, focii suctions

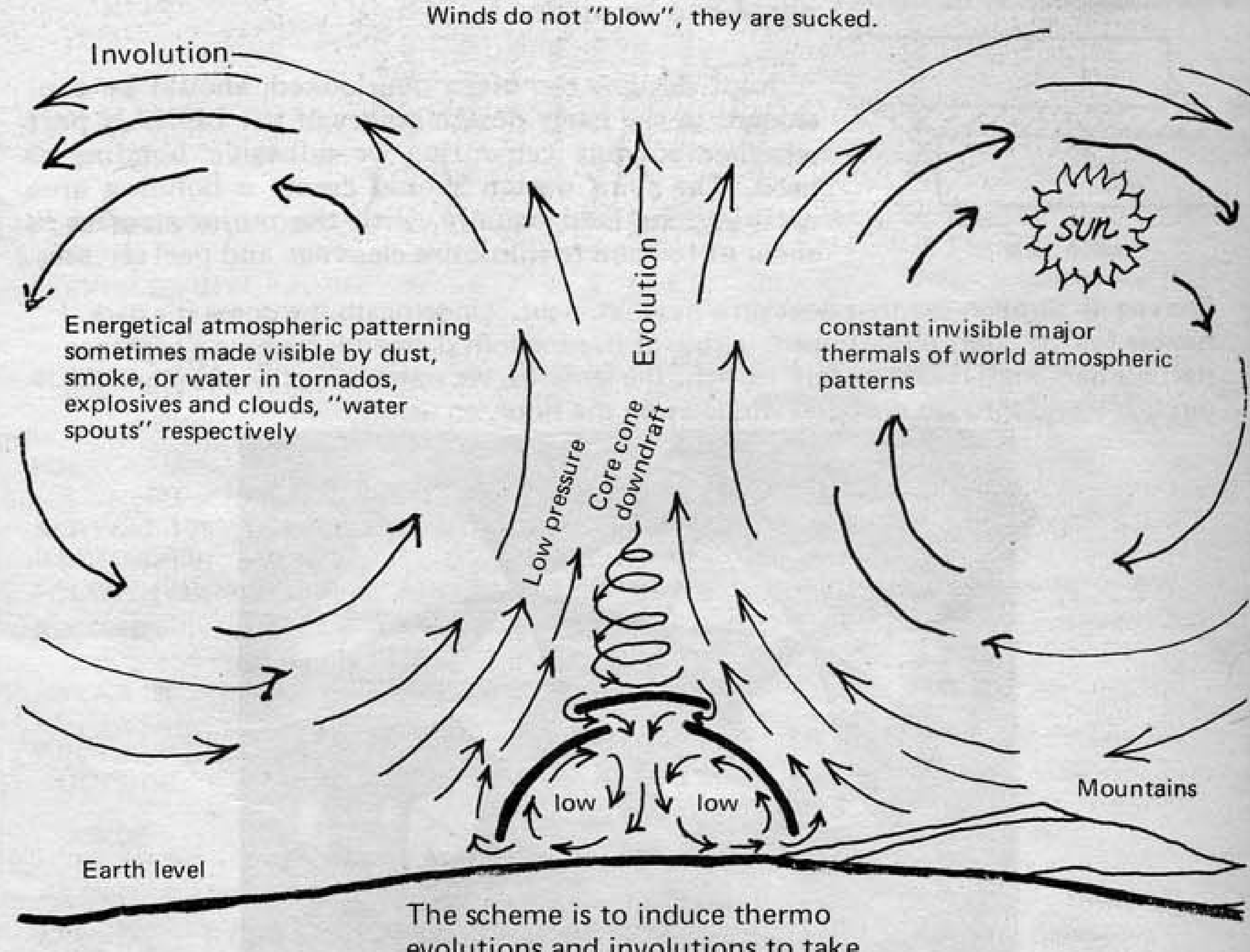


Major Atmospheric Drift

warm
Barometric Lows
suck winds concentrically

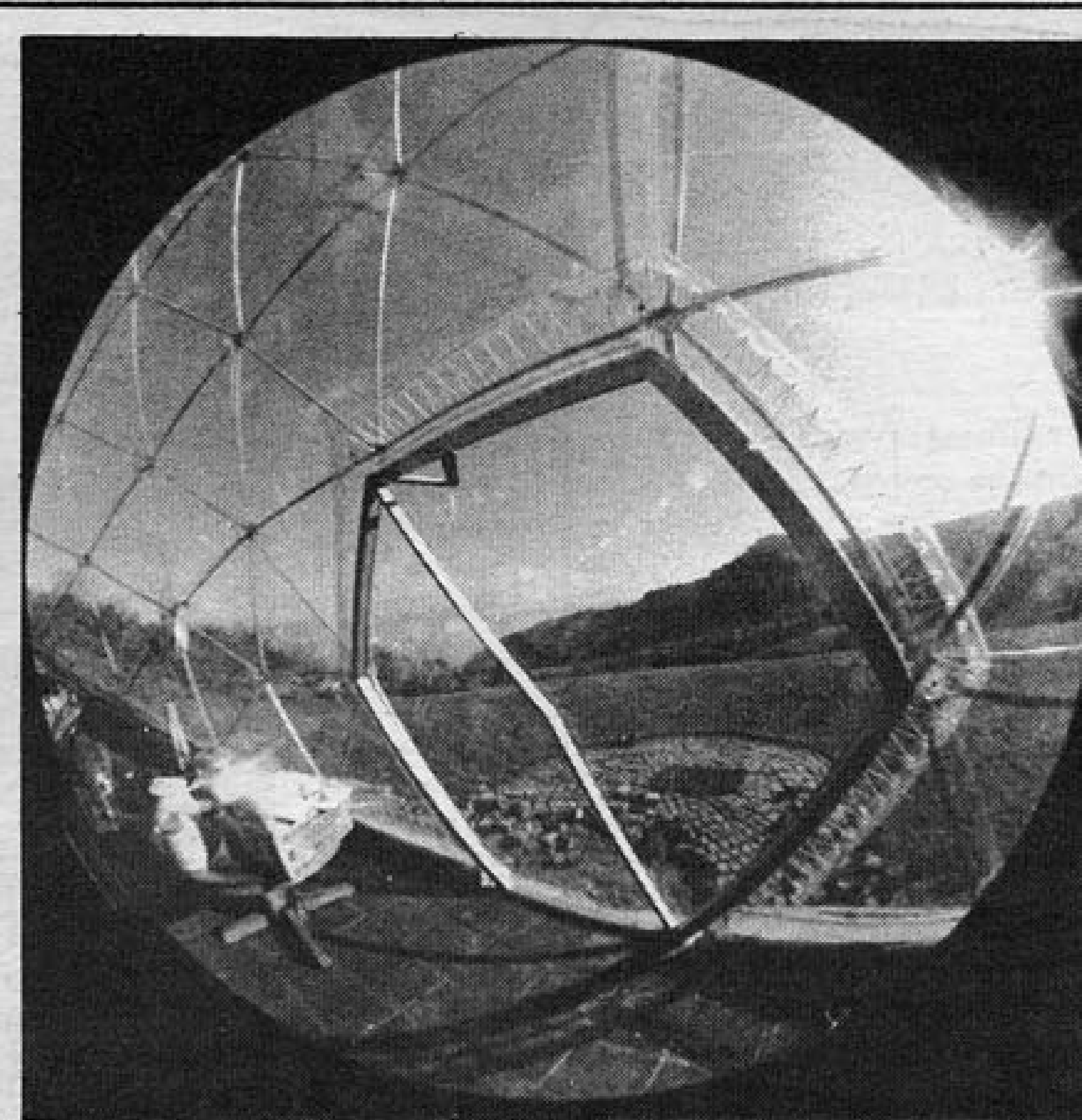
cold
Barometric Highs
yield eccentrically

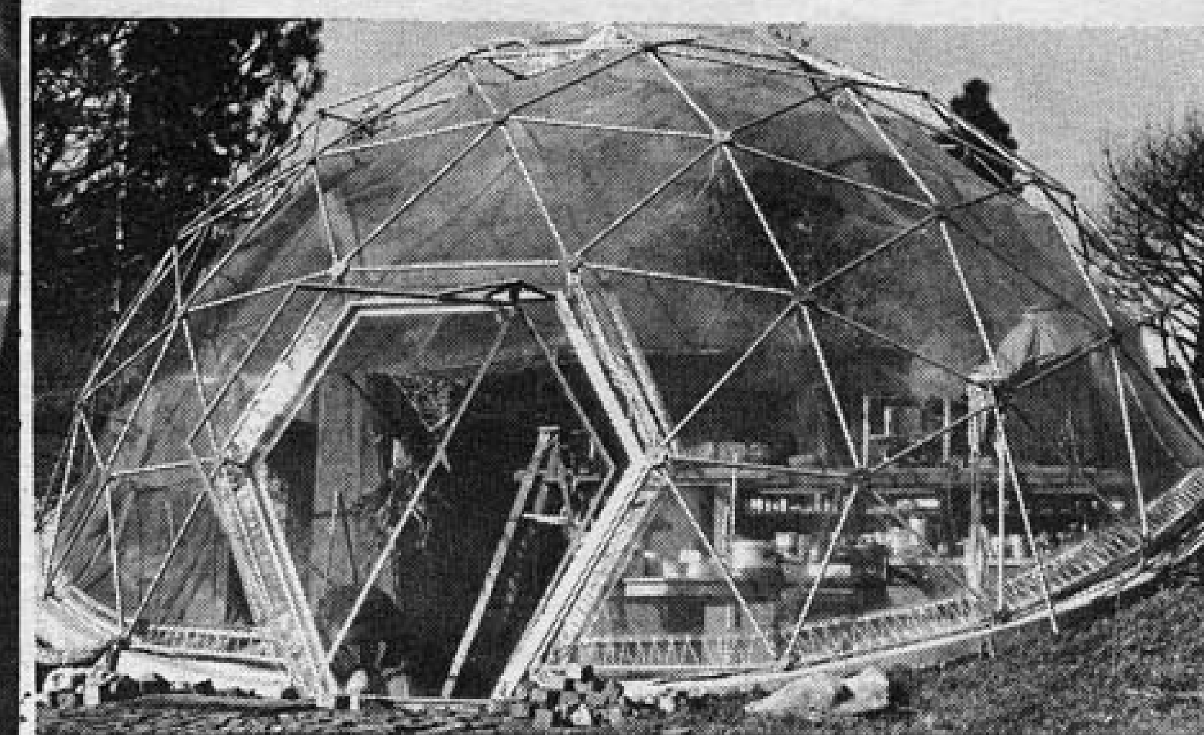
Winds do not "blow", they are sucked.



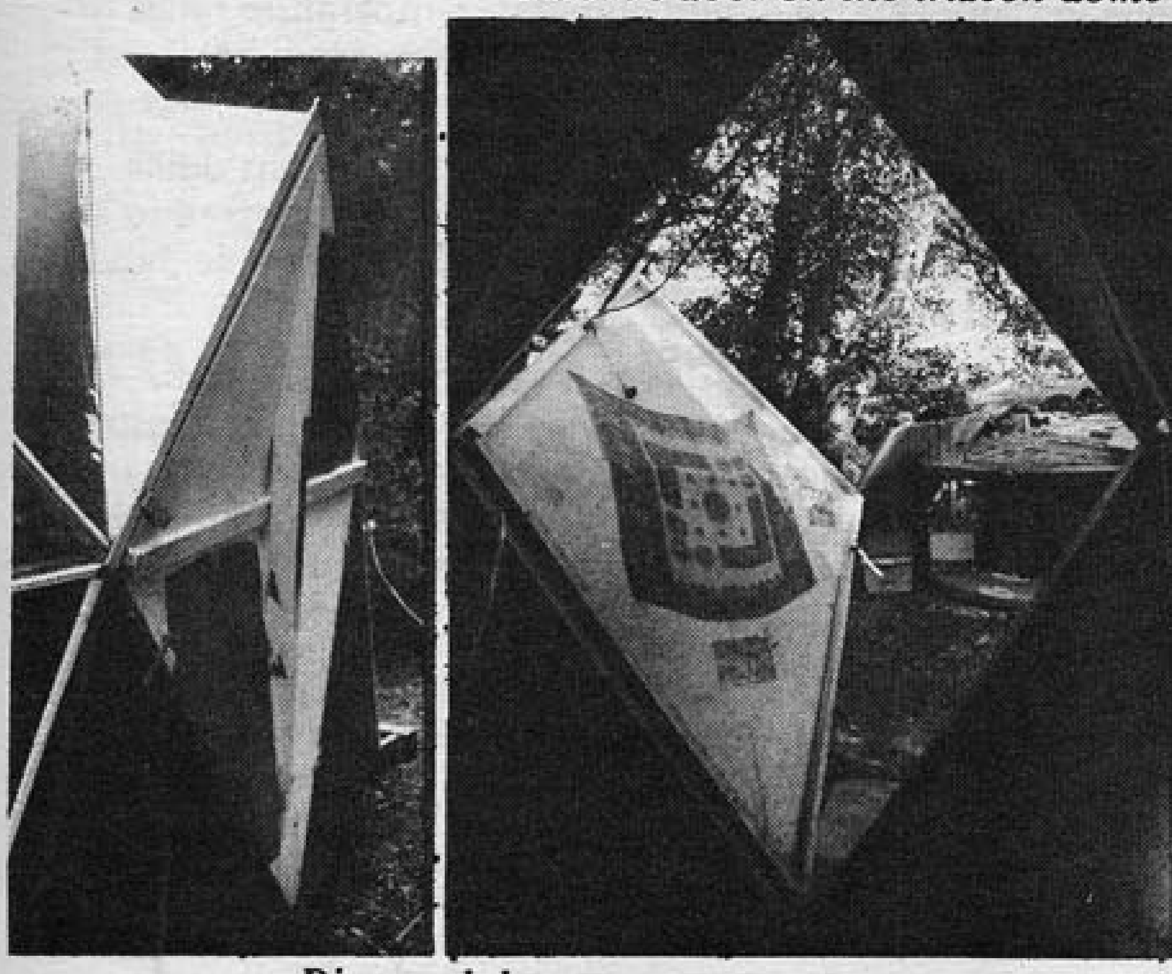

The scheme is to induce thermo evolutions and involutions to take a natural reciprocal course *through* geodesic environments, thus employing the *vacuum* drags of the patterning and its obstructions to pull the interior airs over preferred patterns. This is accomplished through convex-concave *shapes* and dimensions of openings and reflectors.

Robin's door on the triacon dome

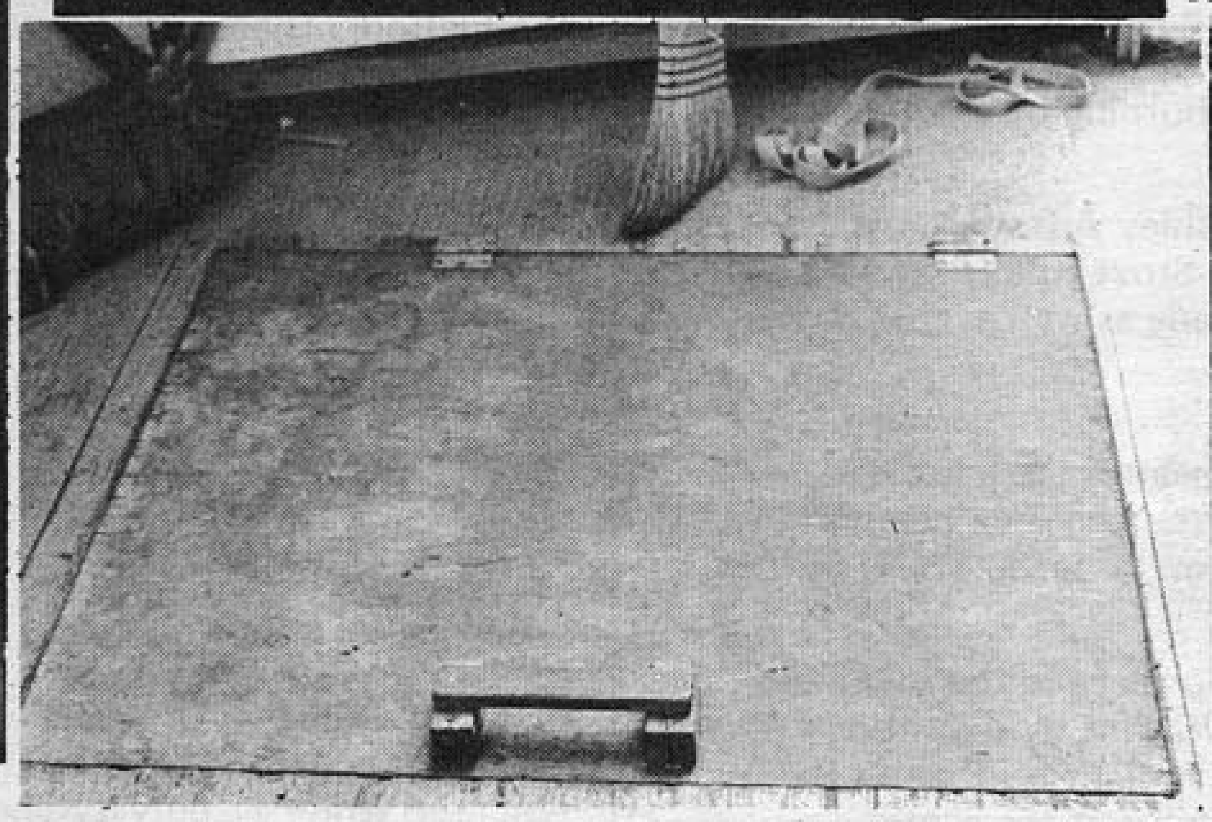


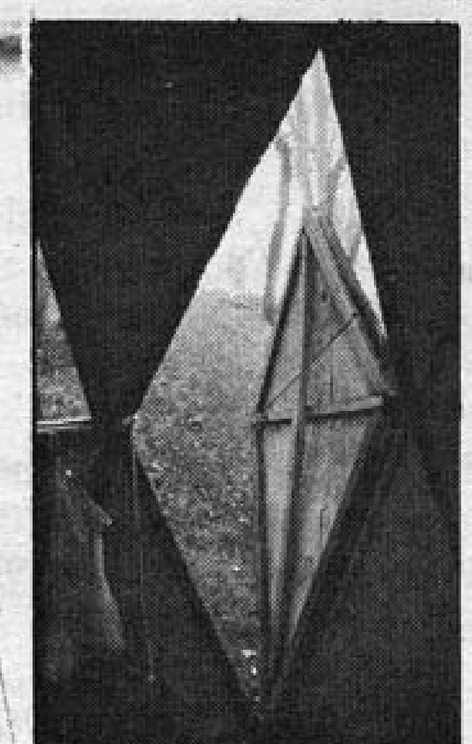


Neill Smith's door: Lexan in aluminum frame



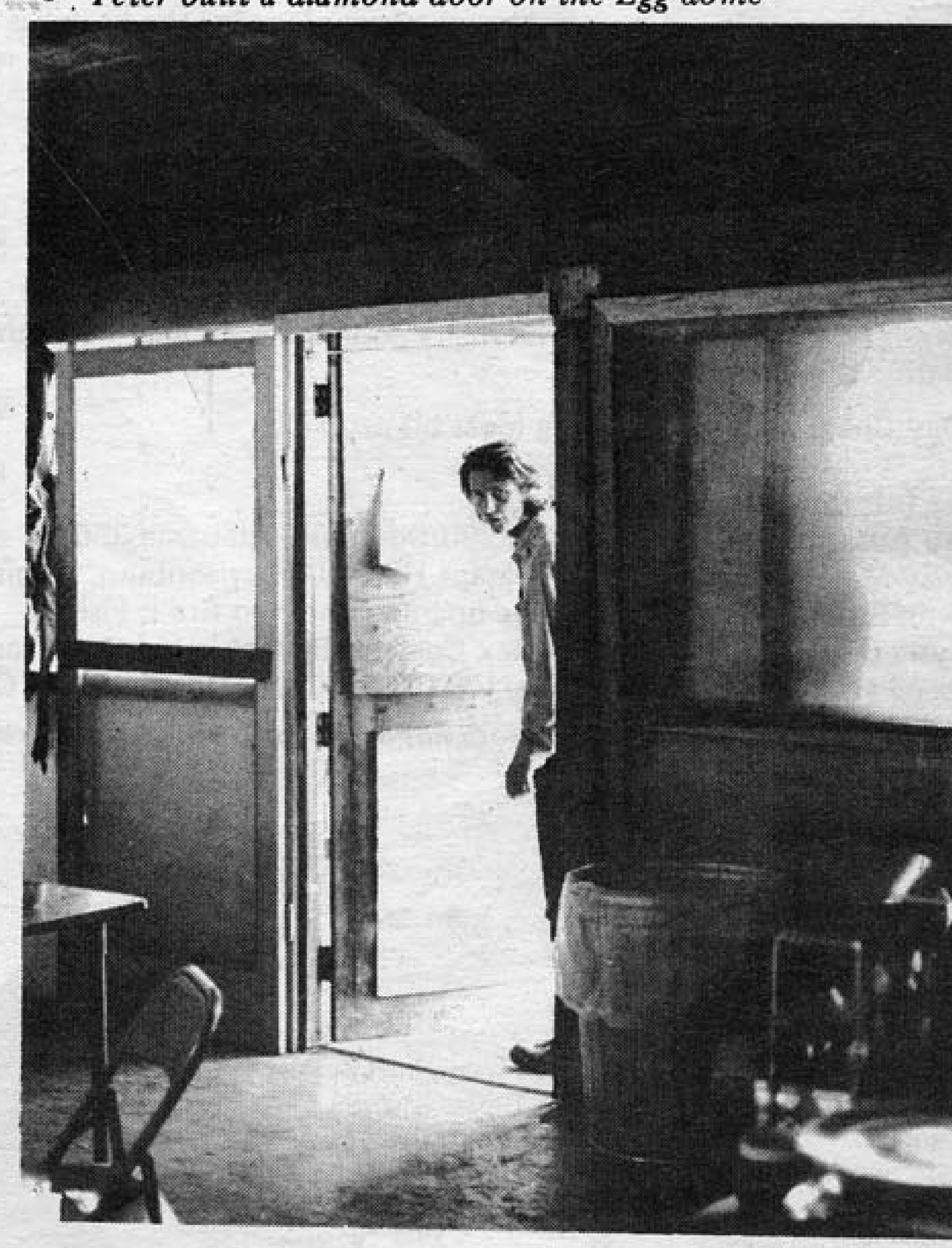
Diamond doors





Peter built a diamond door on the Egg dome

Pillow dome triangular door



# DOORS

The two simplest doors to make into a dome are a triangular door and a trap door:

**Triangle door:** merely hinge one of the point-down triangles—work out a detail for shedding water. This limits the size of things you can bring into the dome, and causes one to stoop each time the dome is entered.

**Trap door:** if the dome is on a hillside, with a wooden floor, a trap door is easy to install and you don't have to cut into the shell. We skilsawed a section out of the 1-1/8" plywood floor, then made doors out of the sawed-out section. The door in my dome is 3' X 5', and opens in two sections. There is a backstop so it doesn't fold all the way down to the floor when open. The door is this big so that a harpsichord will fit through (or a 4' X 8' sheet of plywood) but it's quite heavy and could knock someone out if it fell on their head.

Disadvantages of a trap door are that it uses up floor space (even when closed you don't put anything over it), and it's dangerous unless there's a railing to stop people (especially two year olds) from falling through the open door.

A nice thing is that you can keep firewood under the dome, and get it during rain storms without getting wet.

A good trap door could be made of a sandwich fiberglass panel (you can use corrugated cardboard as stiffeners between the two sheets) or you could use a Sanstruction panel (see p. 86) which would give you a translucent, lightweight door.

If you put a door in the skin, and it is not a simple triangle door, two constructions will be necessary: bracing and a water deflector.

*Bracing:* when you remove struts for the door opening, you'll have to compensate for the loss in strength by bracing.

*Water deflector:* is needed to stop water from running in at the top of the door, and hitting you each time you open the door in the rain.

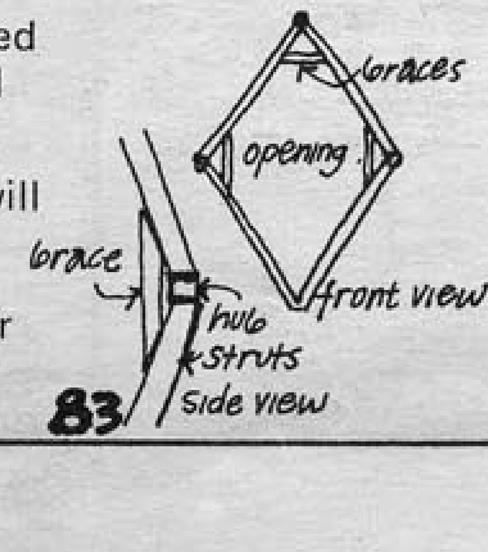
**Diamond door:**
Note that a door made with a hinge on a slant like this will open with gravity, sometimes with disaster if the door is heavy. This can be counterbalanced by a long spring, or a piece of nylon cord (as off a parachute) which will stretch and spring under load.

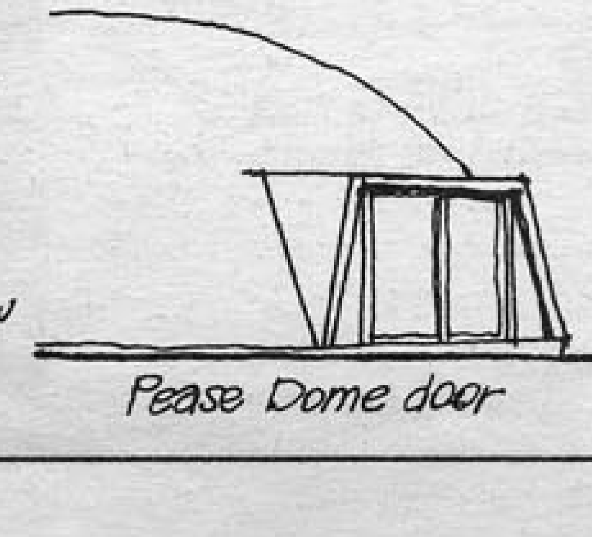
**Robin's door:** another way to make a door (if dome is on hillside) is to use a point-up triangle as the top half of the door, and cut into the dome platform for the bottom half, with stairs *inside* the dome. This door, unlike the triangle or diamond doors, will pass building codes. It can open in 2 sections, like a dutch door.

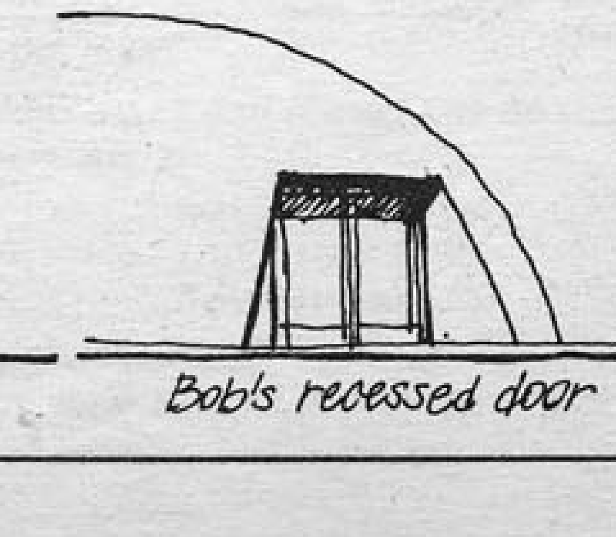
**Rectangular door:** doors in the Pease domes are made by extending a half-hexagon out to a 90-degree wall, then installing standard doors or windows:

Pease dome patent should give you good information on this. See p. 122

**Bob's door:** conversely, you can frame inwards for the door; this way the dome shell is the water deflector.



# HEATING

**Wood stoves**
We live in the woods with quite a few dead trees to cut up, and most of our domes are heated with $15 Wards thin metal wood stoves. These stoves have an air control valve in the front door, and we've installed dampers in the stove pipes: this allows us to control air flow, and thus size of the fire, and is more economical than a stove with no air control. These small stoves heat our 24' diameter domes easily, even with large window areas, although our average winter temperature isn't usually below 35°. You should put a few inches of sand in the bottom of these stoves to insulate against burning up the floor and stove bottom.

In a larger dome, or colder climate you might want to use an Ashley Automatic, a stove with an automatic air control valve, or a Riteway Woodburning Stove; the Riteway is supposed to last longer than the Ashley, which are not being made as well as they were some years ago.

**Propane**
The pillow dome has been heated by a catalytic heater. These heaters use a lot less propane than a regular heater, are silent and supposedly fumeless. Thermex heaters have automatic safety shut-offs, which some domestic brands don't. 12,000 BTU output will run 55 hrs on a 5 gallon propane bottle.

A centrally located heater may be more efficient, but it takes up space in the middle of the dome. Heaters mounted near the wall can be made more efficient by mounting a reflector of foil or thin metal behind the stove and stack so the radiant heat won't be lost through the skin. It may be that the best place for the heater is at the center a few feet from the ceiling. This gives good circulation and an easily made stack while keeping the floor clear.

**Stove pipes**
Where the stove pipe passes through the dome, you must use either a Metalbestos (triple wall) pipe or a piece of ceramic pipe to insulate against fire. Keep a fire extinguisher handy, as fires are going to burn efficiently in a dome.

Ken Kern's *Owner Built Home* has many good ideas on heating, including a heat circulating fireplace. See p. 119.

See Day Charoudi's solar heating ideas on pp. 122.

**Heater Information:**
Ashley Automatic Heater Co./Box 730/Sheffield, Alabama 35660
Riteway-Marco Industries/169 pleasant Hill Rd./Harrisonburg, Virginia 22801
Franklin Stoves are nice—they have opening doors so fire is visible.
Catalytic propane heaters: Thermex Corp./1280 Columbus Ave./San Francisco,Ca. 94133
Kerosene Heaters: B & J Supplies/1701 Clear Creek Rd./Redding, California 96001.

*John's dome in Minnesota has a double barrel stove. See page 56.*

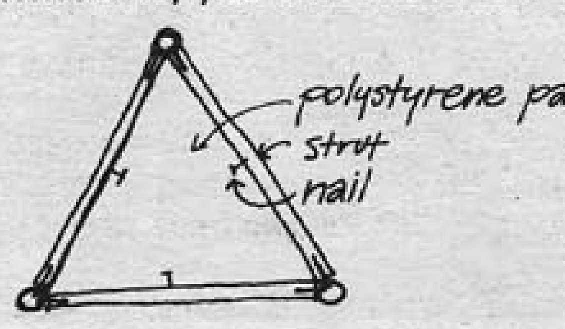
*This hood looks like a good idea for protecting windows and vent*

# INSULATION

Most of this work has been done in California, in a mild climate: temperature range of +30° to 90°F. Thus insulation has not been as critical for us as it is in more northern climates. We have snow only about once a year.

We have received many letters from Canada, and northern states, asking about dome insulation. There is really nothing different about insulating a dome as compared to a conventional house: insulating materials and principles are the same. The dome, however because of its shape, is far easier to heat and insulate.

Plastic foam which can be sprayed, or comes in rigid sheets is very good insulation. Polyurethane foam is the best insulating material known. See pp. 70-73. The advantage of foam (as compared to aluminized fiberglass insulation) is that it's appearance is OK, and you don't have to cover it up with an interior membrane. In conventional homes, there is an exterior and interior membrane, with insulation in between both walls and roof. If you leave out the interior membrane, you save materials and money.

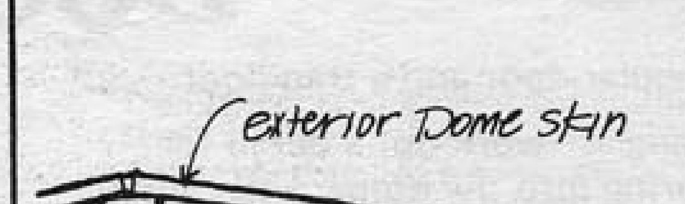


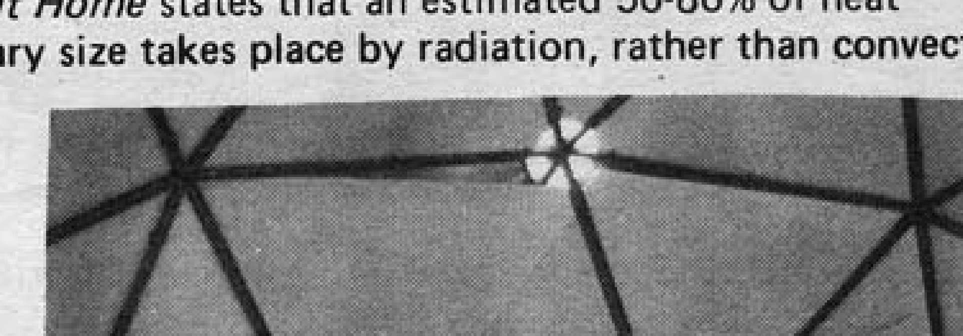

**Rigid foam insulation**
We used white 1" polystyrene board stock (called Dorvon, made by Dow), which we put in with three small nails per triangle. It was cut from 4' X 8' sheets—make a template, cut with a pocket knife to size, cracking them off. We weren't very careful about precise fit. Half pieces can be used under the dome for floor insulation.

We've always lived in old redwood homes until now, and I'd wondered how the white plastic would feel by contrast. Tom Duckworth had mentioned life in a giant Dixie Cup. The white foam seems to emphasize the wood struts, and the dome feels more wooden than plastic. Shiny foam *would* be unbearable for us, but foam—either styrofoam or polyurethane—is not shiny, and fades into neutrality, leaving the wood dominant—a half timbered feeling. It's bright and light, and the foam softens sound bouncing around the dome. In the long run, you'd probably want to panel over the lower courses of the dome, as the foam is easy to damage. If you are going to do this, you could save money by using fiberglass-aluminum insulation under paneling, foam higher up where there is no paneling.

*Check carefully on the burning characteristics of any plastic.* Plastics salesmen are often less than anxious to point out that their product burns. Not only is it important that the plastic not burn, but you should check what happens to it when material around or next to it begins burning. If you hold a match to our insulation, it won't burn, but will shrivel. It will not support combustion, but if a fire got going in the dome, it would melt. We're not satisfied with this situation, and you should make careful tests and think a lot about any plastic material you plan to use. The prospect of melting plastic is definitely scary. On the other hand, polyurethane foam is capable of greater fire resistance, which is rated by "flame spread"—the lower the number flame spread, the greater resistance to fire. Pittsburgh Plate Glass (PPG) foam No. 65058, with a flame spread of 25, is highly resistant to fire. PPG and other companies make paints that resist flames.

In using rigid board insulation, you can increase its efficiency by stapling aluminum foil on the back before putting it in place. Kitchen foil will do—check to see if it's cheaper than buying building foil. Even the thinnest layer of aluminum insulates against heat loss by radiation. *The Owner Built Home* states that an estimated 50-80% of heat transfer across air spaces of ordinary size takes place by radiation, rather than convection.



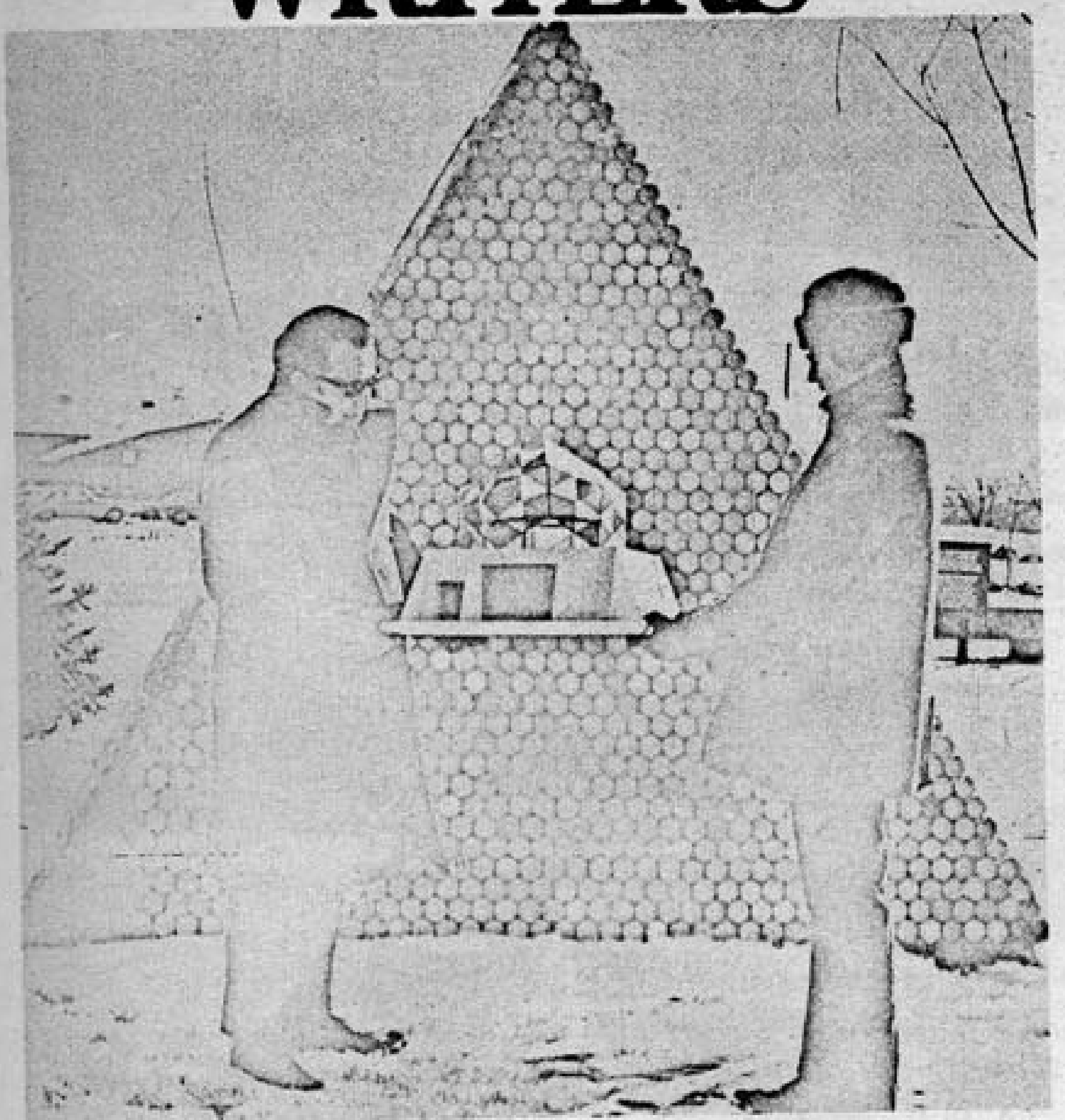
Also, you can increase insulating qualities by leaving an air space between foil and dome membrane say by letting the insulation come out flush with the interior struts.

Another possibility, since buying polyurethane rigid board stock is expensive, would be to pour your own foam board. Write Materials Supply Co. (see p. 86) if you want to try this. With a sun dome type, you could pour the foam directly in the triangles while they are on the ground before assembly. If you had some way of slicing you could pour a huge triangle full (5' high) then slice off 1" or 2" pieces.

**Fiberglass insulation**
Another type insulation is fiberglass with aluminum backing. It is cheaper than foam, commonly used, easy to apply. It comes in rolls, generally of a width to fit in the 14½" space between wall studs. It can be cut with scissors and stapled in place. The aluminum should face in, and you'll most likely want to cover it with an interior membrane—burlap, muslin, painted cardboard, etc. However leaks will be more of a problem here than with foam as the fiberglass and membrane may soak up water.

**Summer Cooling**
Large windows are a real problem in summer See Windows section, pp. 80-81 on shades and placement of windows, and Vents, p. 82. Another factor that will help in summer cooling is for the surface of the dome to be white or aluminum color, reflecting heat rather rather than absorbing.

# WRITERS



## MILLIONS OF POP CANS

*To: Whole Earth Catalog*
*Re: New construction method for geodesic dome skins. Enclosed is a page from CERN, a magazine for high energy physicists, which describes a novel construction technique for making cheap, strong, insulating, weatherproof double skins panels for domes. This is being done at N.A.L. (National Accelerator Laboratory) at Batavia, Illinois, which is the newest and largest particle accelerator in the world. Due to severe budget cuts, the physicists have become ingeneous at doing things better for less. This is an example. The text explains everything and I thought you might be interested*

*The idea is to use empty beverage cans as the core material in building panels. Thanks to standardization of sizes, cans carrying a variety of different labels will all fit together to serve the same purpose. The tops and bottoms are knocked out of them (by a specially developed machine which clears a thousand cans an hour), so that they pass light, and they are assembled into panels by bonding thin glass fibre reinforced plastic sheets over the open ends (see photographs) forming a sandwich about 10 cm thick.*

*First of all, such panels are cheap (a good starting point for any decision at NAL) since their main component, the normally discarded cans, is free. They have proved to be extremely sturdy and well able to withstand wind and snow loads. They are also light and easily handled and can be assembled into panels of virtually any desired shape. If they are used for the geodesic dome of the bubble chamber building they will be in equailateral triangles of about 3 m side. Just as a bonus, they rid the environment of empty cans. Following an appeal for cans, they have been pouring into the Laboratory by the thousands. NAL may well win extra renown as the home of a million pop cans.*

*Brosl Hasslischer*
*Physics Dept.*
*S.U.N.Y at Stony Brook*
*Stony Brook, N.Y. 11790*

## THEATER IN FIBERGLAS

*Thanks to your "Domebook One" and the assistance of a very capable fiberglass manufacturer, our studio is entering the final stages of the production of a six frequency alternate breakdown dome structure of sixty four foot diameter to be used by one of our clients for a theater-in-the-round.*

*The 5/8 sphere is built of one hundred five "sub-icosa" panels (nine to each actual icosa) molded of fiberglass and polyester. Each "sub-icosa" is formed of four of the triangles of the six frequency breakdown and the edge dihedral is structurally reinforced across the face of the "sub-icosa" panel. You can see that, due to repeats, the whole icosa is composed of actually three "sub-icosa" moldings repeated three times. This little trick allows us to make the entire theater using only three molds to make the 105 necessary panels. The financial saving has obviously delighted our client. The cost of each produced panel is quite low because the total material weight is slightly less than 140 lbs.*

*Each of the "sub-icosa" panels is joined to its mate with a simple joint that allows for a "reasonable" amount of construction error without complicating the total assembly procedure. Weather sealing, at least in prototype tests, has been very acceptable.*

*I can truthfully say that if we hadn't seen your first publication we would still be intimidated by domes, geodesics, icosahedrons, and all the other words that are now familiar to our staff. The hints, material sources, and inspirational beginning that we found in your "Domebook One" have been sincerely appreciated many times over.*

*Thank you,*
*Paul B. Smith*
*Smith Design Studio*
*Ann Arbor, Mich.*

## CONCRETE STRUTS

*What do you think about making the struts from precast concrete? I realize that it will be heavier than wood struts. It will save though money and trees.*

*Truely yours,*
*Daniel Altman*
*St. Paul, Minn 55105.*

## DRY SHAKES

*Built a 24' Pacific dome shingled with Cedar shakes last fall. Very warm & dry thru Washington winter. Thanks so much for Domebook I, and now II.*

*Justine Hanusz*
*Springdale, Wa. 99173*

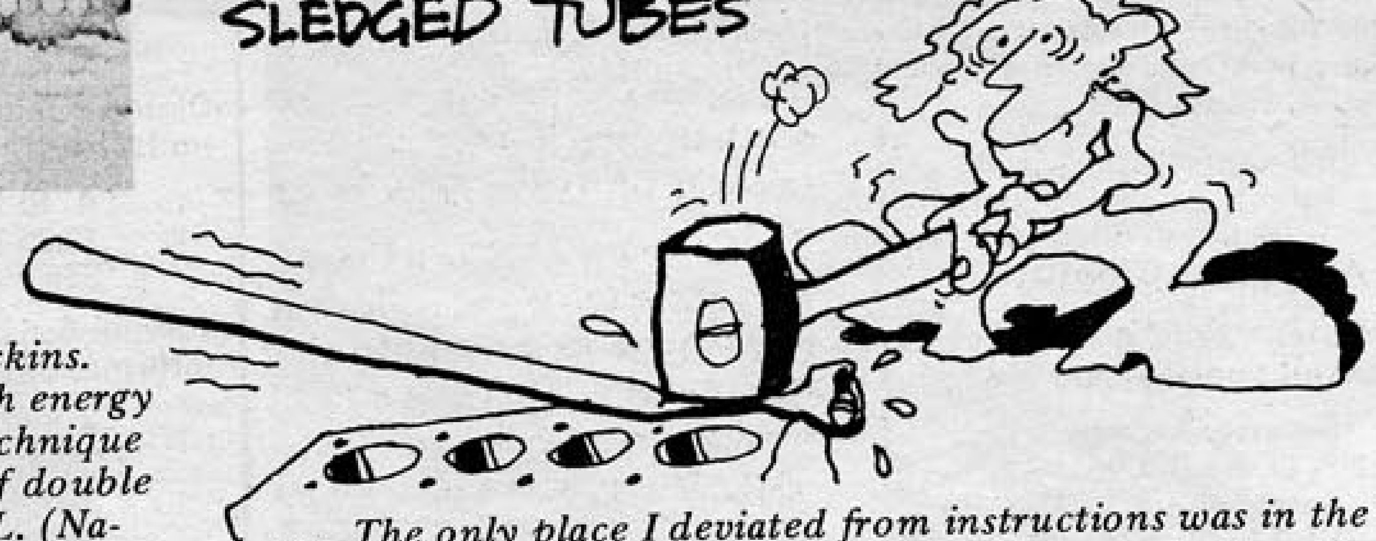
## BOILED PVC

*I'm surprised that nobody, anywhere, notices that Triacon has a hemisphere (interrupted by 2 ½-diamonds) if you take the midpoint between two pents as a zenith. This will be an edge with 2v, a hex with 4v. But wait, I take that back, it is silently incorporated into the 2v paper model on p. 125.*

*I'm currently experimenting with PVC. If anyone wants to know, there's a simple method of flattening ends so you can drill and bolt like tube-frame. Stick as much of the end as you want to flatten – say 4" – into boiling water for 10 seconds. Lay it on a brick, press with another brick. If if isn't really flat simply repeat. (It had better be really flat or it will crack under bolt pressure.)*

*Hugh Kenner*
*Santa Barbara, Ca.*

## SLEDGED TUBES



*. . . The only place I deviated from instructions was in the manner in which I squashed the ends of the struts. I could not find a vise strong enough to flatten them, so I used a 16 pound sledge hammer. I layed the strut end on the side of a discared automobile engine block and hit it a few times on each side, getting a surprisingly neat, smooth, and thin squash. I believe this to be the fastest way manually to do it, but you get a pretty tired arm.*

*Thank you*
*William M. Johnson*
*Penns Grove, NJ 08069*

## PLYWOOD CAULKED

*Replying to your letter of March 15, with reference to a sealer for a 24 ft. dome, we suggest the following procedure:*

*Apply our flexible CAULK-TEX at all the seams BEFORE nailing down your plywood. This is the simplest way and it will form a seal automatically. If it is not done in this manner it will become necessary to "V" out the seams and then apply our CAULK-TEX. By applying it as you are placing down the plywood, it is easier, and more effective, and you can use a putty knife for its application. If the surface surrounding the seam area is messed up a little, with the Caulk-Tex, this can be sanded down after it is cured.*

*After the dome is put up and caulked with Caulk-Tex, we advise applying one or two coats of GLUVIT over the entire plywood roof. When completely cured, lightly sand to get rid of the gloss and apply a good grade paint or epoxy paint (vinyls not recommended as they do not bond well to epoxies). This will provide a leak-proof dome for many years to come.*

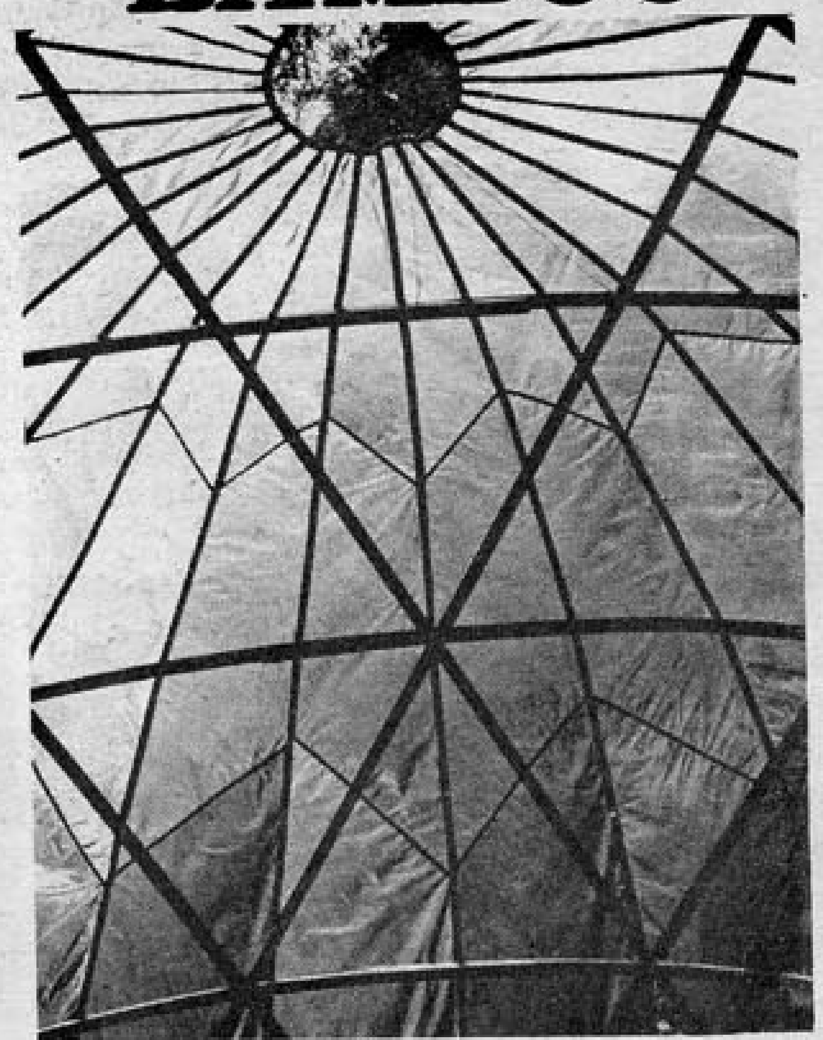
*Your very truly*
*Ralph Travers*
*Travaco Laboratories, Inc.*
*345 Eastern Ave.*
*Chelsea, Mass. 02150*

## DOME COULD FLOAT

*Easy-Deck is best for making domes as tight as boats. If you turn my dome over it will float. Available from the Thorp insulation Co., 2741 South Yates Ave., L.A., Cal. G.E. makes a silicone roofing. Same stuff thats in Sweets. Its also good but no better and costs 3 times as much.*

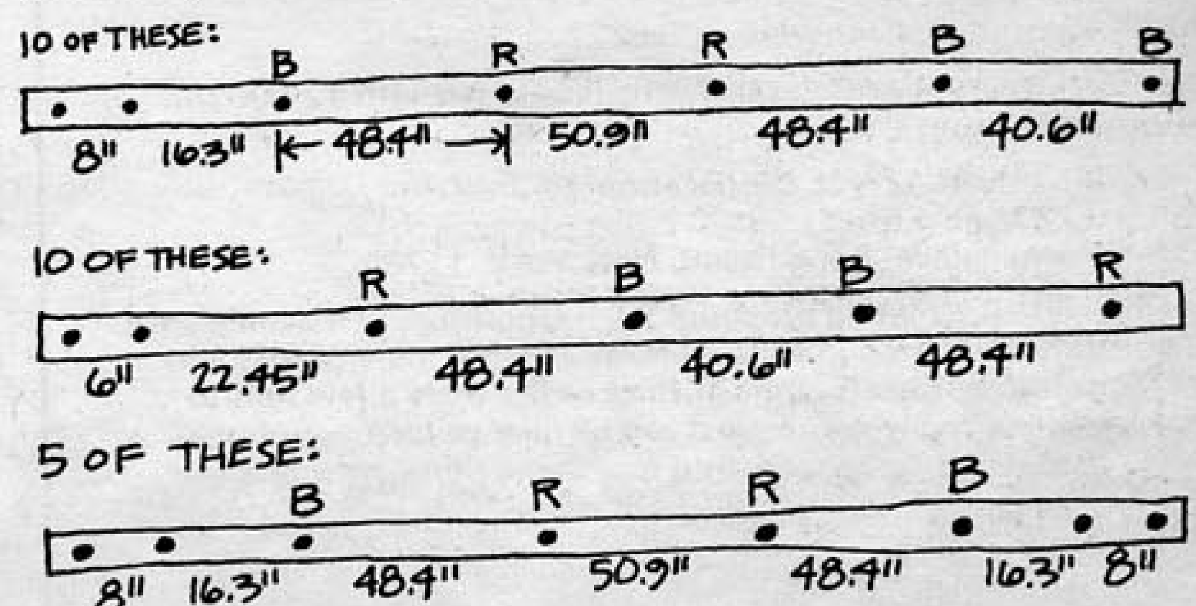
*Richard P. Harvey*

# 1x2 BAMBOO



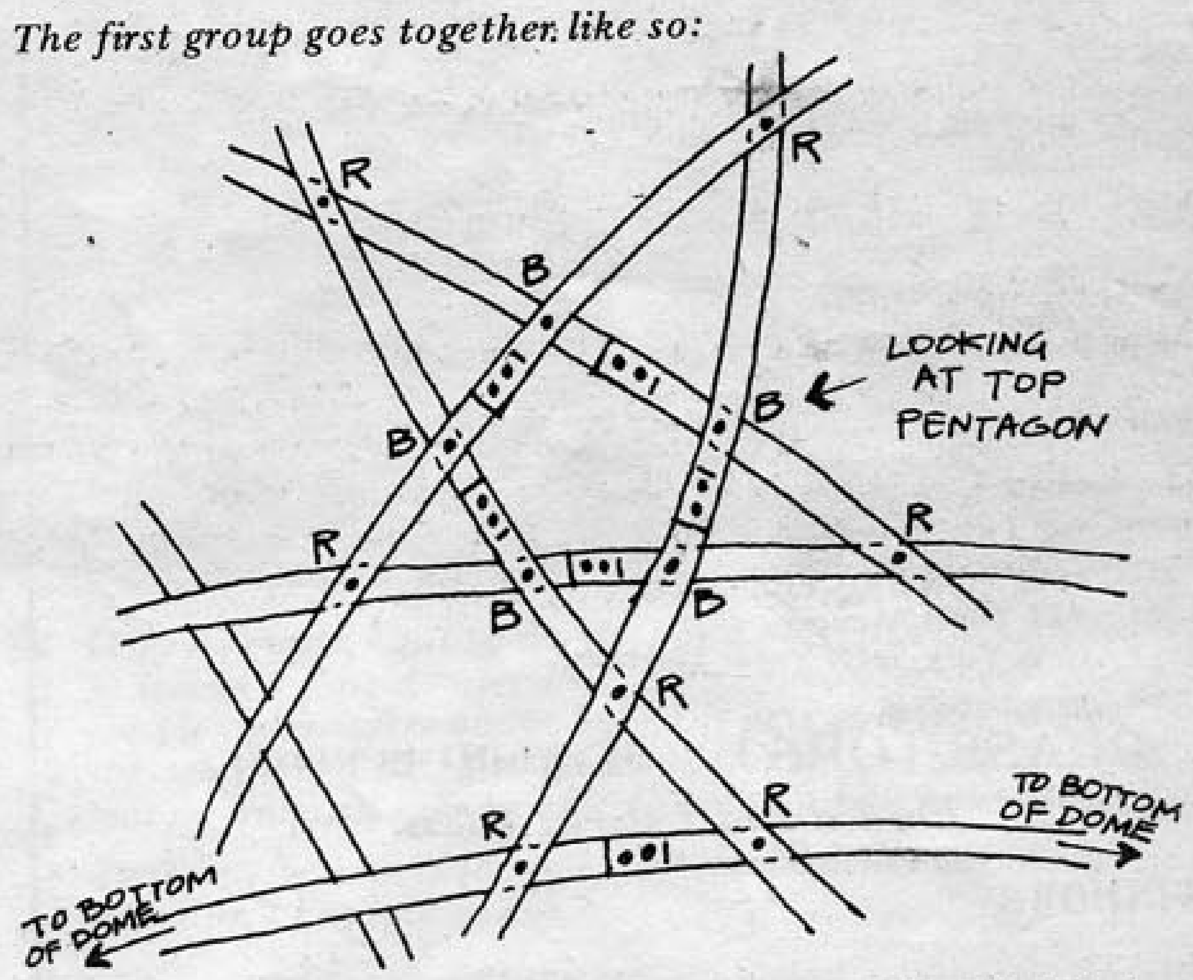
Wayne has built several variations of the Bamboo Dome, p. 95, which he describes here:

*Instead of bamboo, I used 1" x 2" strips (1" x 4" ripped down the middle). For a 26' dia. 3/8 sphere, you need the following number of strips with holes drilled at each point.*

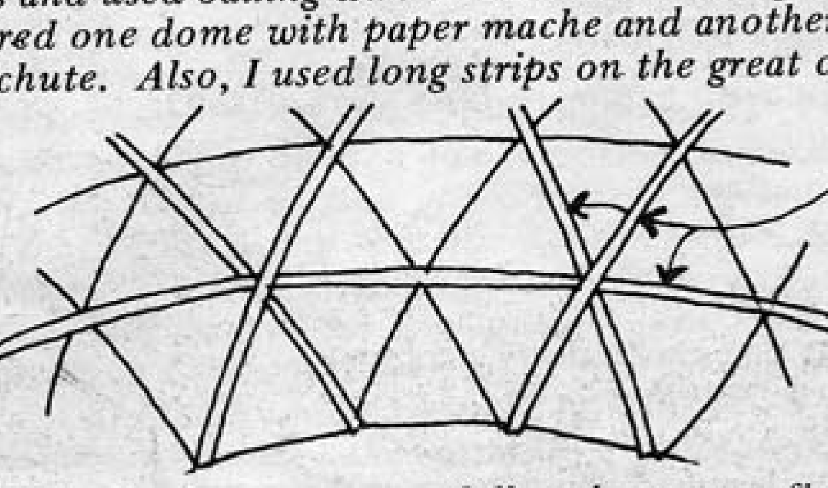



*Mark and drill one and use it as template for all the others in group.*

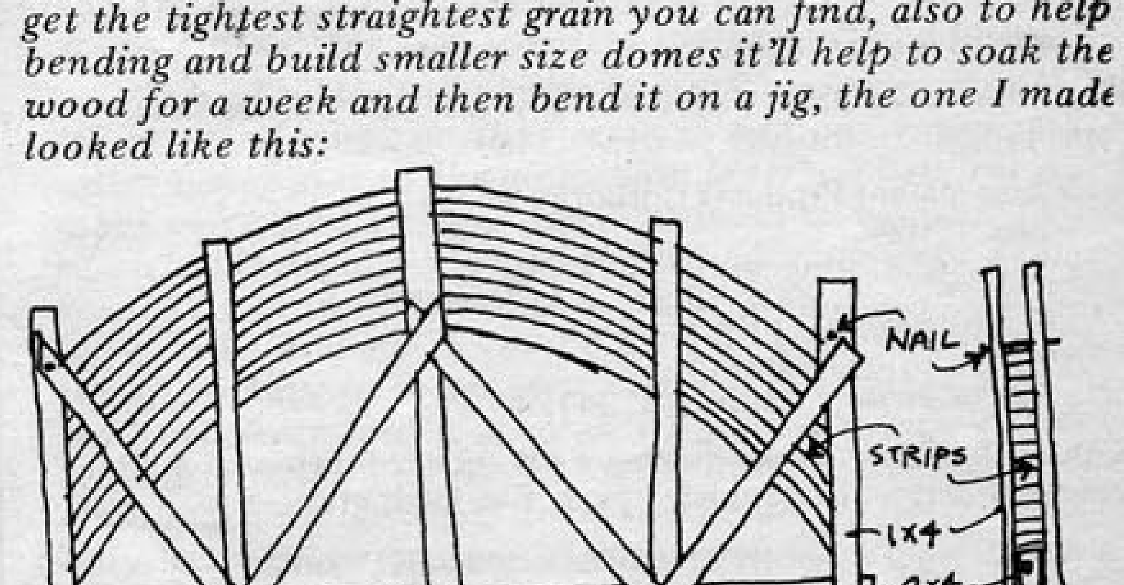
*The first group goes together like so:*




*The last group goes around the bottom: I drilled 8th inch holes and used bailing wire to connect the strips. I have covered one dome with paper mache and another with a parachute. Also, I used long strips on the great circle arcs:*



*to fill in the hexagons carefully select green fir and get the tightest straightest grain you can find, also to help bending and build smaller size domes it'll help to soak the wood for a week and then bend it on a jig, the one I made looked like this:*




*Cost of frame is around $15 and it ought to be strong enough for ferro-cement.*

*Wayne Cartwright*
*1000 Alba Road*
*Ben Lomond, CA*

*P.S. I'm putting one of these up Friday for performers dining place at Joan Baez benefit for farmworkers.*

### RIGID SKIN MATERIAL

Fome-Cor board, type 327W .200" thick flat sandwich laminate of unicellular polystyrene foam between 2 layers of paperboard. 4' X 8' sheets $5 per sheet in 20-sheet quantities, $3 in 200-sheet quantities. Brochure Fome-Cor Board's tech bulletin No. 6113A:

Fome-Cor Board
Type 327W
Monsanto Company
200 N. 8th St.
Kenilworth, New Jersey 07033

Steel foil corrugated board (up to 70" width) being produced in widths 30"-34", lengths 24"-96", with larger sizes available on special order. Cost about $80 per thousand sq ft. This company is experienced at scoring, slotting, joining techniques and can do same in plant with sufficient instructions; ask for sample:

First Container Corporation
Box 303
Fort Worth, Texas 76101
Attn: Don S. Leaman, President

Fiberglass structural panels-doors, skylights:

Sanstruction **PLEASE SEND FOR PAMPHLET.**
702 North Bend Rd.
Cincinnati, Ohio 45224

Silicone coated plywood—architectural specs and application instructions from

Weyerhauser Company
Box B
Tacoma, Washington 98401

Glass reinforced thermoplastic sheet "Azdel"—very strong, developed for autos:

G. R. T. L. Company
No. 1 Gateway Center
Pittsburgh, Pennsylvania 15222

Reinforced acrylic structural sheets, tensile strength 12,000 psi. Information from

American Acrylic Corporation
173 Marine Street
Farmingdale, Long Island, New York 11735

Rigid vinyl—fascinating brochure from Goodrich, "Designing with Rigid Vinyl." Comes in rods, extruded shapes, pipe, sheets and molded shapes. Sheets come in thicknesses from a few mils to several inches, many colors, and can be *heat-welded* with hot-air guns. You might be able to weld together a dome membrane at triangles' edges:

B. F. Goodrich Chemical Company
3135 Euclid Avenue
Cleveland, Ohio 44115

Acrylic Plastic sheet, Kydex 100, Kydex 5,000, resistant to ultraviolet. Technical data from

Rohm and Haas Company
Independence Mall West
Philadelphia, Pennsylvania 19015

Teflon, Plexiglas, fiberglass, Mylar, vinyl, foam guns, etc. A complete catalog of plastic materials and prices:

Plasticraft, Incorporated
2800 North Speer
Denver, Colorado 80211

Best plywood for domes: Duraply flat panel siding is exterior Douglas Fir plywood with phenolic resin-fiber surface, designed for severe weather exposure. Guaranteed against delamination for life of building. Brochure from

U. S. Plywood Corporation
777 Third Avenue
New York, New York 10017

**GLASS TOPS** FOR SKYLIGHT PURPOSES.
***Leaded and Colored Glass.***

### WINDOWS

Plexiglas information (see also pp. 92-93)

Rohm and Haas
Independence Mall West
Philadelphia, Pa. 19105

Polycarbonate (Lexan) information (see also pp. 92-93)

General Electric
One Plastics Ave.
Pittsfield, Massachusetts 01201

Butyrate information from

Eastman Chemical Products Incorporated
Kingsport, Tennessee 37662

Flexible vinyl:
—4 mil optically clear, lasts about 1 year in direct sun, 6¢ sq ft, can order by mail:

Wards Farm Catalog.

—15-20 mil, wavy clarity, lasts several years in sun, 8-10¢ sq ft, depending on quantity:

Transparent Products Corporation
Box 15924
L. A., California 90015

Transilwrap West Corporation
1579 Custer Avenue
San Francisco, California 94124

—both of the above companies have a number of different window materials—aluminized mylar, Lexan, plexiglas, etc.

Clear UPVC rigid vinyl, flexible plasticized vinyl from

Scranton Plastic Laminating, Incorporated
Plastic Sheet Products
3216-18 Pittston Avenue
Scranton, Pennsylvania 18505

Skylight Designer's Handbook—excellent booklet on glass and plexiglas details: **My Specialty is Artificial Light.**

O'Keefe's Incorporated
75 Williams Avenue
San Francisco, California 94124

### FLEXIBLE SKIN MATERIAL (FOR TENT DOMES)

Armor Shell—dacron or nylon fabric coated with .004 mil PVC. Rolls 54" wide, 100 yards long. Somewhere between 10-20¢ per sq ft. Sample book from

Cooley Incorporated
7300 Artesia Blvd.
Buena Park, California 90620

Weblon—similar to Armor Shell, info from

Astrup Weblon Industrial Fabrics
Cleveland, Ohio 44113

Shelter-Lite—vinyl coated fabrics with polyester substrate. Materials 7026, 7124, 5022 seem appropriate for skin material. 10,000 yards of No. 3022 were used for the double skin of a geodesic dome at a New York World's Fair. Heavy duty, relatively expensive. Info from

Domestic Film Products Corporation
M. L. MacKellar Associates
16250 Meyers Rd.
Detroit, Michigan 48235

Swirles and Company
900 N. Alvarado
L. A., California 1 90026

Coated fabrics (ripstop nylon, vinyl coated fiberglass, silicone rubber coated dacron, etc.) Brochure: "Coated Fabrics for Industry" from

3M Company
Film & Allied Products Division
1601 South Shamrock Avenue
Monrovia, CA 91016

Parachutes: 24 ft. diameter canopies, white and in good condition. $22.50 plus postage and tax from

Security Parachute Co.
P. O. Box 3096
San Leandro, CA 94578

All types of mylar and other skins. Laminates of mylar with dacron scrim, rip stop nylon with metallized mylar one side, etc. Exotic and expensive stuff. Info from

G. T. Schjeldahl Company
Northfield, Minnesota 55057

Glue for fabrics—Belt Bonding Cement

Power Lines
245 W. 25th St.
NYC, New York 10001

Plastic-reinforced industrial fabrics:

Sun Chemical Corporation
185 6th Ave.
Patterson, New Jersey 07524

—See also, Wards and Sears catalogs for canvas.

—See yellow pages for awnings, industrial covers, pool covers, etc.

Acetate, Rayon, Nylon, Saran, Chromspun, etc. information. List of manufacturers and basic principles of manufacturing and use. Brochures, "Man-Made Fiber Fact Book" and "Guide to Man Made Fibers" from

Man-Made Fiber Producers Association
350 5th Avenue
New York, N. Y. 10001

## Electric Elevator

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**Remember Well This Address.**

### FOAM

Good source for low cost foam and good advice on proper technique:

Lloyd Fox
Douglas and Sturgess
730 Bryant Street
San Francisco, California 94107

Pour and spray foam; Speedhide latex fire retardant paint with flame spread of 10, can be sprayed on foam.
Pittsburgh Plate Glass is one of the foremost and knowledgeable foam manufacturers. They have some excellent free information on foams and foam paints. Technical information bulletins on Selectron Resin Products and Selectrofoam Resin Products. Brochure "Selectrofoam Rigid Urethane Foam" has comparative chart of all insulating materials. Information from

Materials Supply Company
Box 28307
Sacramento, California 95828 **FIRE-FELT**

Or

PPG Industries
One Gateway Center
Pittsburgh, Pennsylvania 15222
Attn: Resin Products Sales

Ask Dow for information on 3 types of rigid foam: styrofoam, Thurane (polyurethane), and Dorvon.

Dow also makes Deraspan Room Liners, a sandwich panel of styrofoam, faced on both sides with plywood, asbestos board, al aluminum, glasbord. Information and samples from

The Dow Chemical Company
Construction Materials
Midland, Michigan 48640

Rigid foam insulation

Western Foam
464 Victory Avenue
South San Francisco, California 94080

Rigid foam boardstock:

Apache Foam Products
Division of Millmaster-Onyx Corporation
1005 North McKinley Road
Belvidere, Illinois 61008

General Plastics Company
3481 South 35th Street
Tacoma, Washington 98409
Attn: L. W. Schatz

### SEALANTS

Thiokol Joints Design Digest for Polysulfide Base Compounds

from Thiokol Chemical Corp.
Box 1296
Trenton, N. J. 08607

Technical data: Extrusion chart shows how much caulk is needed per lin ft of joint; coverage chart shows coverage per gallon for various film thicknesses.

from Harold A. Price Co., Inc.
P. O. Box 1389
Richmond, CA 94802

Brochure: "Seven Steps to Sure Sealing", on Dow Corning 780 Building Sealant

from Nearest Dow or Price

Access info on silicone, polysulfide, polyurethane, and acrylic caulks on p. 90.

Elastron rubber foam coatings

United Paint Manufacturing, Incorporated
1130 E. Sprague Avenue
Spokane, Washington 99202
attn: Technical Coatings

Closed cell neoprene tape 3/16" X 1", stickum one side about 7¢ lin ft, from **Boiler and Pipe Coverings**

A. B. Boyd Company
1235 Howard St.
San Francisco, California 94103

Weatherban one-part sealant, Scotch Seal Metal Sealant, other information from

Adhesives, Coatings and Sealers Division
3M Company
2501 Hudson Rd.
St. Paul, Minnesota 55119

### TAPES FOR DOME SEAMS

Fab-Dek: 35 mil Hypalon impregnated with neoprene. 3" wide roll, 11¢/lin ft. Adhesive $4.50/gallon. F.O.B. plant

Miracle Adhesive Corp.
27279 Industrial Boulevard
Hayward, CA 94545
or
250 Pettit Avenue
Bellmore, L.I., N.Y. 11710

Fiberglass tape with isopthalic resin. Brochure from

TAP
1710 E. 12th Street
Oakland, CA 94606

Over 100 various pressure-sensitive tapes. Brochure: "Tapes for Industry" from

3M Company ***Send for Samples.***
320 Shaw Avenue
South San Francisco, CA

Elastron rubber foam coatings and tape for dome seams:

United Paint Manufacturing, Incorporated
1130 E. Sprague Avenue
Spokane, Washington 99202
Attn: Technical Coatings Division

Celastic tape is used by Geodesic Structures, Inc. of Bound Brook, New Jersey for sealing plywood domes. Info on tape from

Degusso Company
No. 2 Pennsylvania Plaza
Madison Square Center
New York, New York

Cybond 4546 polyurethane contact adhesive can be used to adhere flexible tape or thin rubber, then painted with Polane polyurethane paint, from

Fiberlay, Incorporated
1158 Fairview North
Seattle, Washington 98109

Catalog of pressure sensitive tapes. Vinyl, polyethylene, double faced tapes, electrical tape, etc. from

Arno Adhesive Tapes, Incorporated
Michigan City, Indiana 46360

### FIBERGLASS

Fiberglass, polypropylene, other fabrics, tapes, resins:

Abe Shuster Fiberglass
6211 Telegraph Avenue
Oakland, California 94609

Excellent fiberglass info, polypropylene, Dynel fabrics, different resins, useful data. Marine Buyer's Guide, 75¢ from

Defender Industries, Incorporated
384 Broadway
New York, New York 10013

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### MISCELLANEOUS

Strap and strapping tools:

A. J. Gerrard and Company
400 East Touhy Avenue
Des Plaines, Illinois 60018

Check yellow pages (*strapping*) for closest location, or other companies.

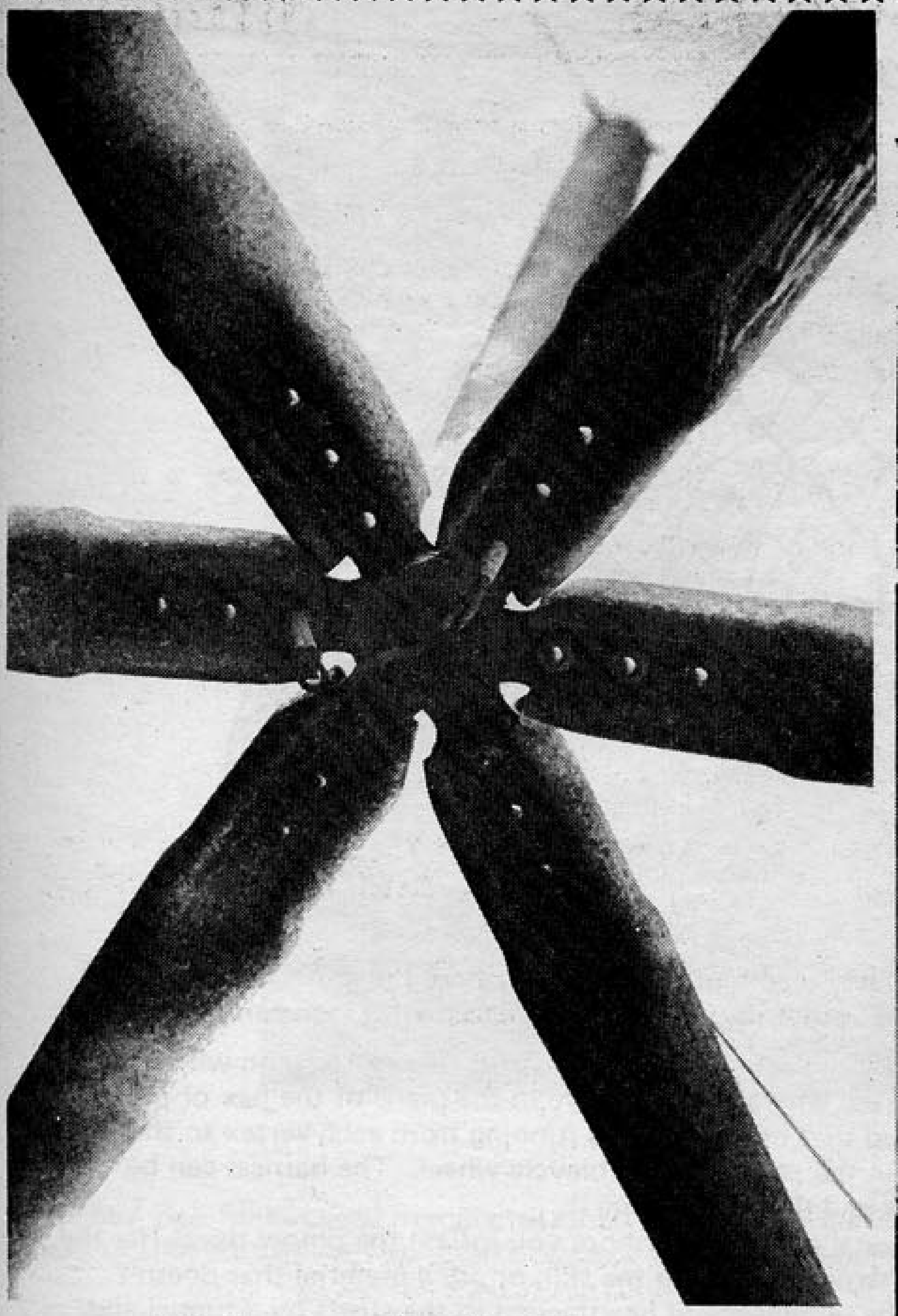
Rust-proof MONEL staples, staple guns:

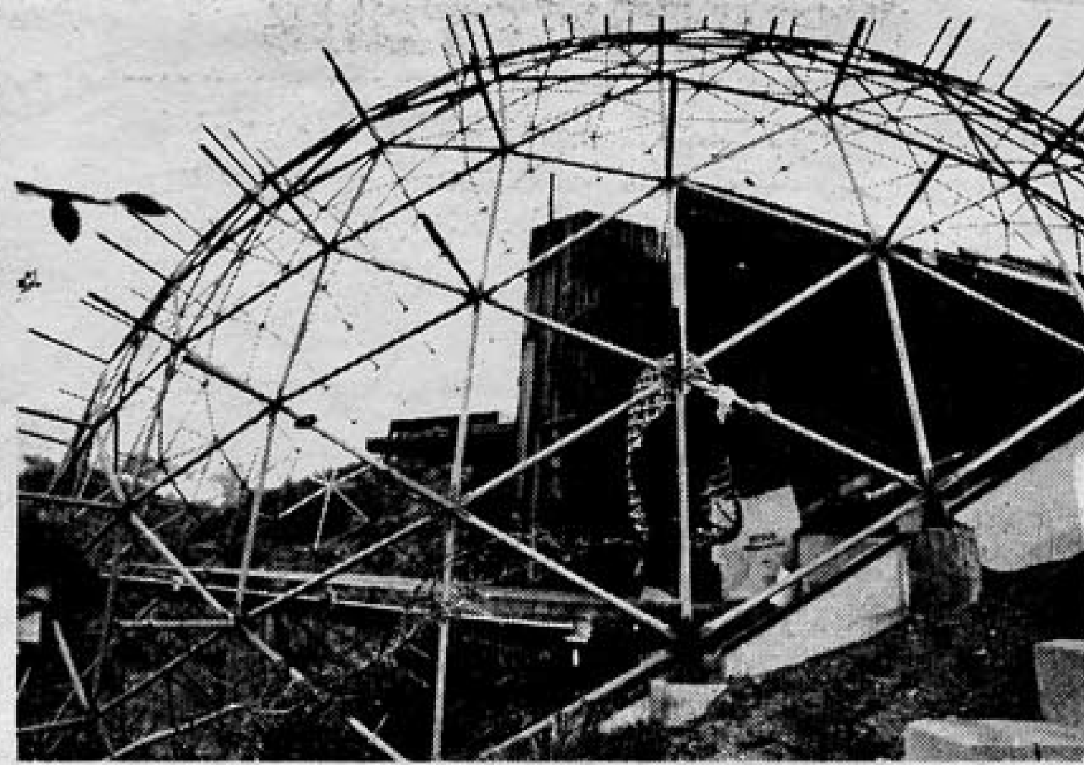
Duo Fast California
1465 Third Street
San Francisco, California

Extrusions: rubber and synthetic, about 40¢—$1 per ft, making the mold is surprisingly cheap, as low as $40. This means you can design an extrusion tailored to your needs. From

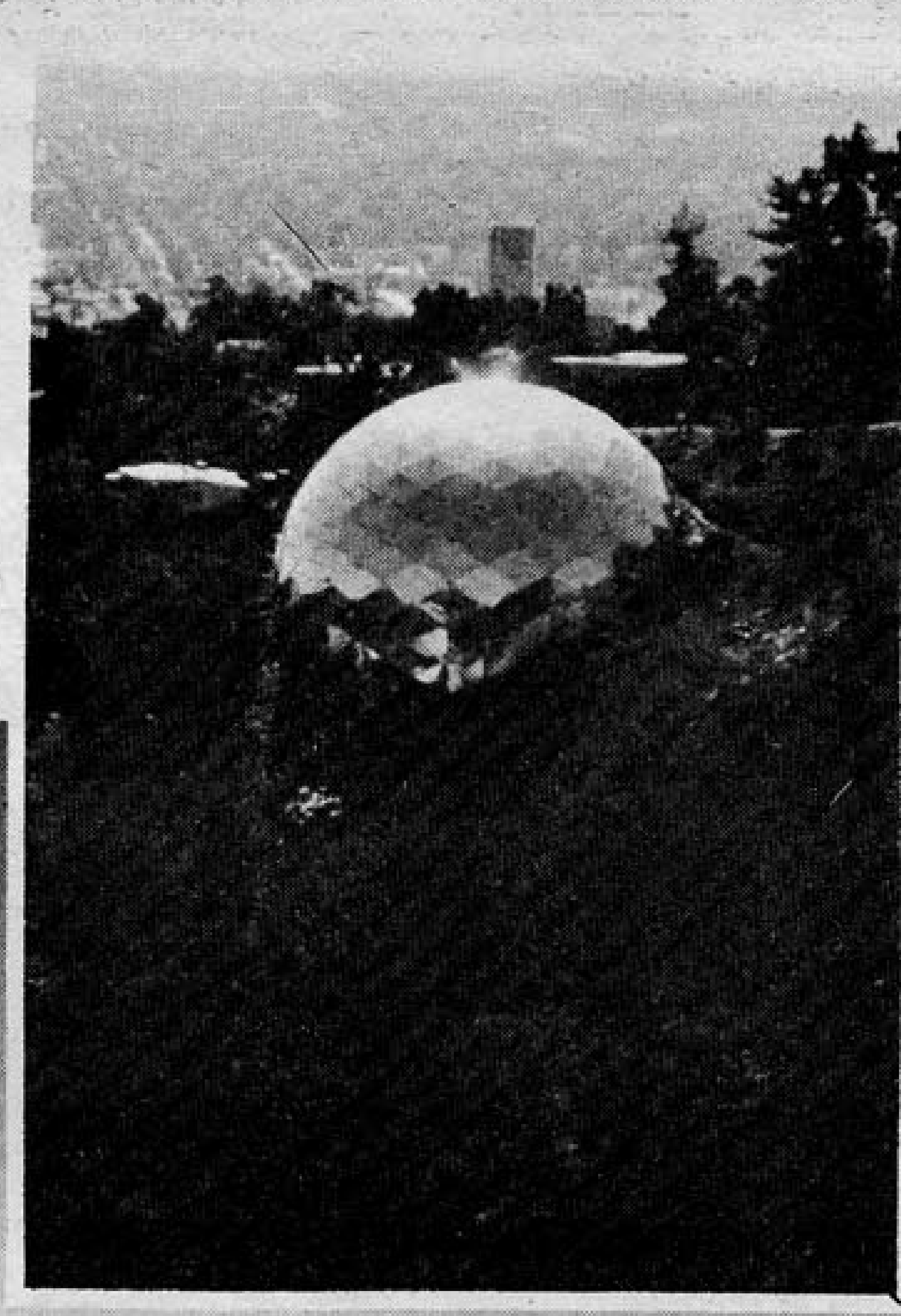
Wefco Rubber Manufacturing
1655 Euclid Avenue
Santa Monica, California 90404

**95% Fine**





Dome was once covered with aluminzed mylar



## ★★★ Hollywood Hills Dome ★★★

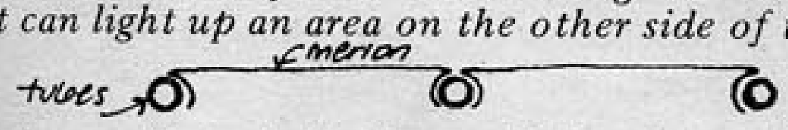
In the hills above Hollywood, on a very steep slope is a spectacular dome, originally designed by Jeffrey Lindsay and built in Montreal. The dome was later shipped to L.A., and put up on the hill site by Bernard Judge. To convince city officials of the dome's strength, Judge put 14 tons of weight on the structure, and the dome sagged 3/100ths of an inch over 24 hours. The dome has a colorful history. Once it was abandoned, and used as a lookout by burglars to see when neighbors left their homes. After several robberies, neighbors petitioned City Hall to demolish it. Literally one day before demolition, Allen and Jerry Davidson bought it, have been working on it since, and are presently getting ready to cover it with an all plastic aluminized skin. The struts which stick out, giving it a sea urchin look, are connected with cables to the frame, and provide added triangulated tensional strength to prevent the dome from popping in. Following are portions of letters from Allen Davidson.

★★★

*Dome is 49 ft dia. 1/2 sphere. Two levels inside with small crow's nest library above those and large dirt basement, so will be 4 levels one day. 50 ft is good size for 2 people. Plenty of room, but a family with children might wish for more unless room is used more efficiently than in this one.*

*Frame is all 1½" liteweight aluminum tubing. Vertical sprits hold guy wires which put the entire shell under a tensile stress instead of compression. 1000 lb dome will hence support a load of 112,000 lbs! Was load tested with 30,000 lbs and didn't even sag. The wires are what do it, but that sort of strength isn't really needed and the wires and sprits cause all sorts of glazing problems if you want a good appearance. Tubes are from about 40"-52" long and there are 10 different size triangles. All tubing is straight and crimped at the ends—slightly different than yours. The polycarbonate windows are being applied to the exterior surface of the frame. This is best for looks, but applying it to inside surface could be done much easier and be better for sealing. Polycarbonate will probably be 1/8" Merlon by Mobay.*

*Don't consider just aluminizing a few windows as the light transmitted by the others will raise the interior brightness to a point where you will be getting excessive reflections of chairs, newspapers, etc. in the aluminized windows to a point where you won't be able to see out. All windows must be tinted to the same degree. The kaleidoscopic effect is* absolutely fantastic *(!!) and can be used in thousands of ways if your whole dome is mirrored inside; for instance one light bulb in a hidden spot can light up an area on the other side of the dome.*




*Windows will probably be applied as above. Each triangle will have a U-shape channel bent all along each edge which will be force fitted to the tube frame. This will be a very solid fit even though not fastened in any other way. People outside shouldn't be able to easily pry a unit out, but inside with some trouble you could. Looser panels can be designed specifically to be easily opened. A piece of resilient foam or rubber tape taped to the frame will be squeezed tightly enough to seal out rain. Joints will have a cast seal unit.*

*If you have ever seen 1/8" polycarbonate windows you will be seriously discouraged by their lack of flatness and resultant optical distortion—a distorted* reflection *that is. By forming the U-shaped channels properly, I think we can eliminate it by causing the panels to bow outwards—which on a spherical dome looks better than their natural inward concave bow.*

*By not bending the U-channel quite as far as desired, when you clip it to the frame it will have to bend a little more, stressing the window causing it to bow outwards. If you bend it too much, you reinforce the concavity.*

*U. V. stabilized polycarbonate should last in excess of 5 years but I don't know how long. We are using it because of the strict building codes and fire laws here in the hills. The 1/8" should be absolutely unbreakable by any human being. I know I have hit it over and over with a hammer. It only dents, like a piece of metal. Should keep the thieves out, anyway.*

*After this one is done and I get a long vacation, am planning on doing an all plastic dome. It would be much less hassle as the frame only gets in the way.*

*The mylar surface blinds the neighbors, but is fantastic for reflecting the weather. When the sky is blue, the dome is blue. At sunset it's orange. When the lightning flashes, your house flashes right back. Although it's still miles from being finished, I think Bucky's very first dome is the most fantastic house in the world. Living in a transparent house when it rains has got to be one of the most beautiful experiences in life.*

*Within a year, Mobay and GE will be out with polycarbonate with a glass-hard protective coating to prevent scratches. To remove deep scratches in any if you get them, just hold a match next to the scratch. It will melt and flow. To bend the stuff, a Bernz-O-Matic torch like from Sears does great. Just lay the piece over a form, heat it, and it forms itself right to the pipe. Very easy, but it is very easy to get it too hot and get bubbles by using a blowtorch. They just make too much heat. We're going to use nichrome wire which heats up when electrified.*

*Controlled via a Variac rheostat you can control the heat precisely. The wire can be had in asbestos insulated "heating tapes" available from scientific lab supply houses. Bending polycarbonates can also be a problem unless done rapidly because they contain moisture which can go opaque or cause bubbles if you let it heat too long. Dried for about one week at 150°F eliminates most of that though. I make it sound like polycarbonates have lots of problems. Only a couple. But so do glass and plexiglas. Who'd want to live in a glass dome when as SST flies overhead? Same for plexiglas—after about 1 year it gets as brittle as glass in the weather. Coated polycarbonates should last 20 years and no one will ever be able to break into a house that way.*

*That briefly covers the polycarbonate field I think. If not, don't hesitate to ask.*

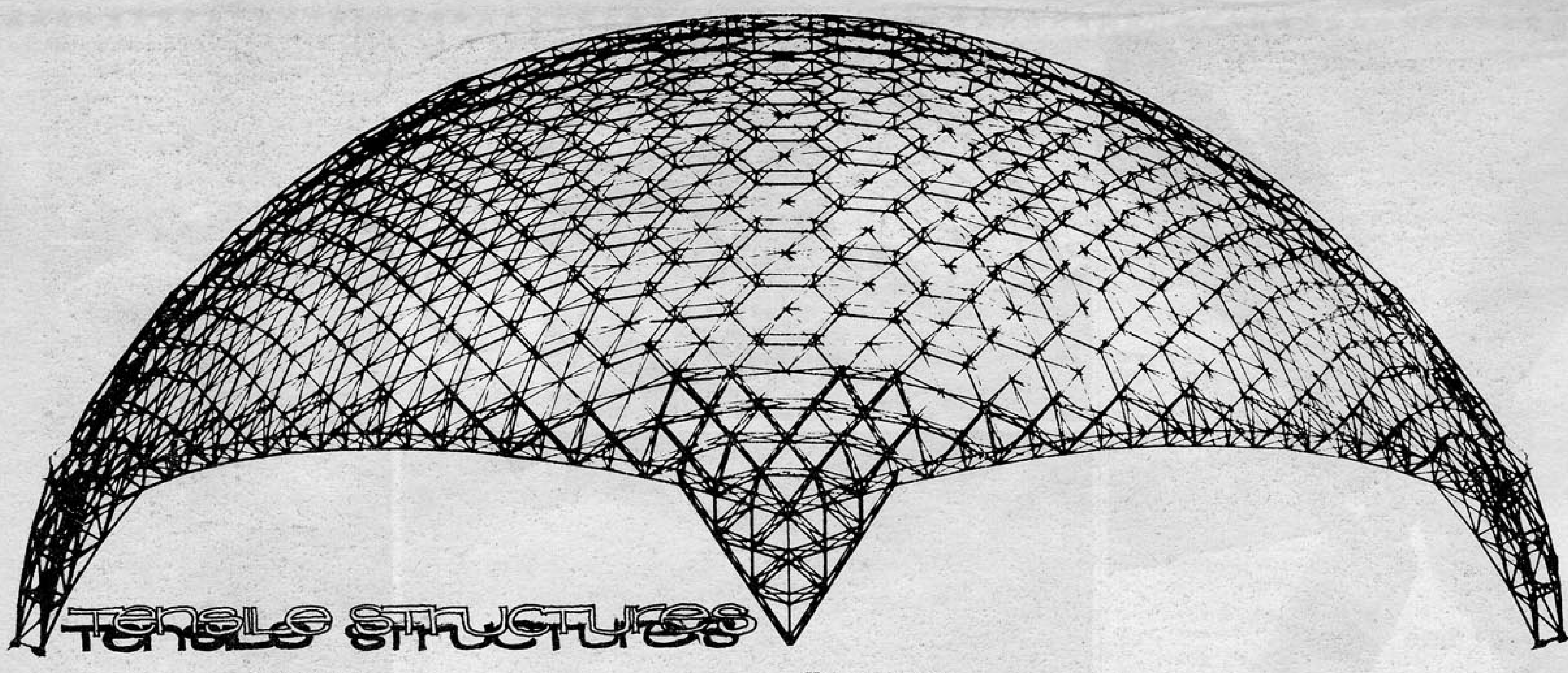
★

*...Although living in a transparent dome might give rise to desires for more privacy, it also will give rise to persiration. Under a hot sun, the interior can get hot enough to melt plastic alarm clocks (it actually happened). These requirements of privacy and temperature control are solved perfectly by a thin film of aluminized Mylar. This reflects 85% of all incoming heat and light, which is approximately what a pair of silvered sunglasses will do and is exactly the percentage desired for windows. Aluminized Mylar has a super thin coating of aluminum sandwiched between two layers of Mylar which are each 1½ mils thick. The Mylar laminations protect the aluminum, however Mylar is no longer readily available in a weather resistant, U. V. stabilized version so deteriorates if used outside in only 8-10 months. When it gets wet the Mylar absorbs minute amounts of water (*no *plastic is 100% waterproof, although for practical purposes they seem to be), and when this water penetrates to the aluminum layer, a chemical reaction takes place which causes the aluminum to vanish. This results in regular, non-reflective Mylar after only a few month's exposure to weather. A version is available which has an adhesive which can be used on glass successfully, but there have been problems with it in contact with polycarbonate so it is more difficult to laminate to polycarbonate. The method used here is to laminate the aluminized Mylar in between two layers of polycarbonate, only having it in contact with the polycarbonate via pressure instead of using any adhesive. The absence of an adhesive also improves the optical qualities of the windows...*

*Regards—*

*Allen Davidson*
*Los Angeles, California*

NOTE: Complete details of this dome's problems and solutions, and results of covering materials' tests will soon be available in a small booklet. For information write to: Transparent Domes / P.O. Box 825 / Los Angeles, California 90028.



# Tensile Structures

Hans Meyer

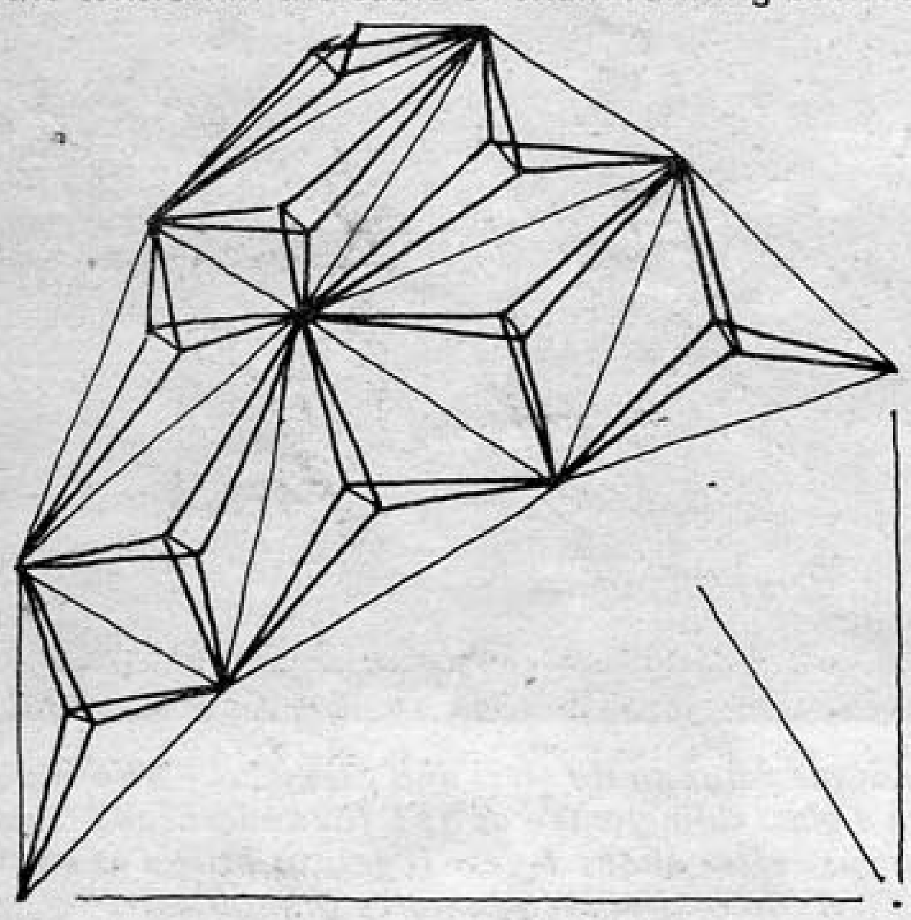
Planes, like birds, have a skeleton, a bone structure that supports a skin. Man-made structures seem to be imitating nature more and more. Fundamental structure in more complex mechanisms is being identified—different materials are being used for the functions for which they can be best adopted.

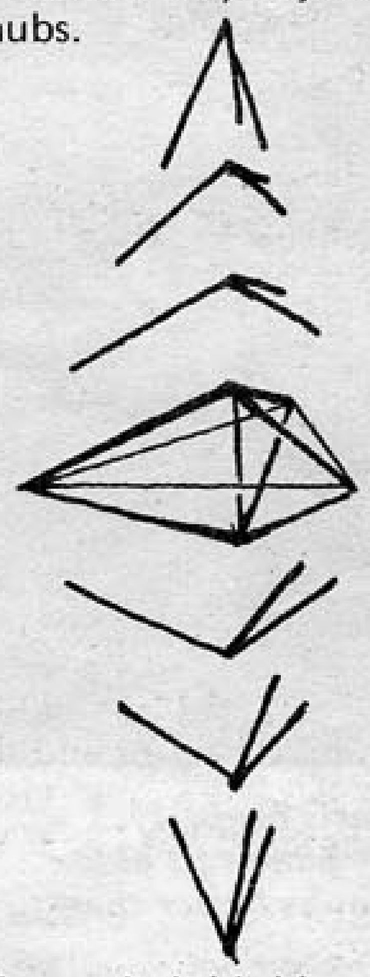
The tension and compression in structures like domes can be isolated to make lighter, more skeletal-like structures.

**Spider frame dome**

The 5/8 truncation of the domes at Pacific gives a strong feeling of inside-ness and outside-ness. The floor plans are nearly circular, the shell comes back on itself. This dome would be a way to get away from this closed-ness. It's a take-off from the low truncations that Temcor uses.

The shell would be made out of a nicropressed cable net with wood or aluminum tube tripods clipped in. The cable net will be a 3 or 4-frequency alternate 3/8 truncation. Each triangle of the net is tensed by inserting opposing tripods and pulling the central hubs toward each other. The tension in the cable triangle can be varied by adjusting the tension in the cable or chain running between the tripod hubs.





The struts give a diamond breakdown. A one-piece hyperbolic paraboloid skin will go on the outside. A second skin with built in insulation can go on the inside.

Two pent vertices could rest on supports at floor level. The other three points would be elevated—the center point could be 5 or 6' off the ground. The space between the dome and the floor will be a non-structural wall—window or wood, set back several feet from the edge of the dome shell.

The problem of head room near the edge of a small diameter, low truncation is eliminated by tilting the perimeter. The secondary wall means that you can use a one-piece skin to get away from the leakage problem and still have ample light and air flow.

The floor on the raised side can extend out beyond the perimeter of the domefor a close by, outside, level area.

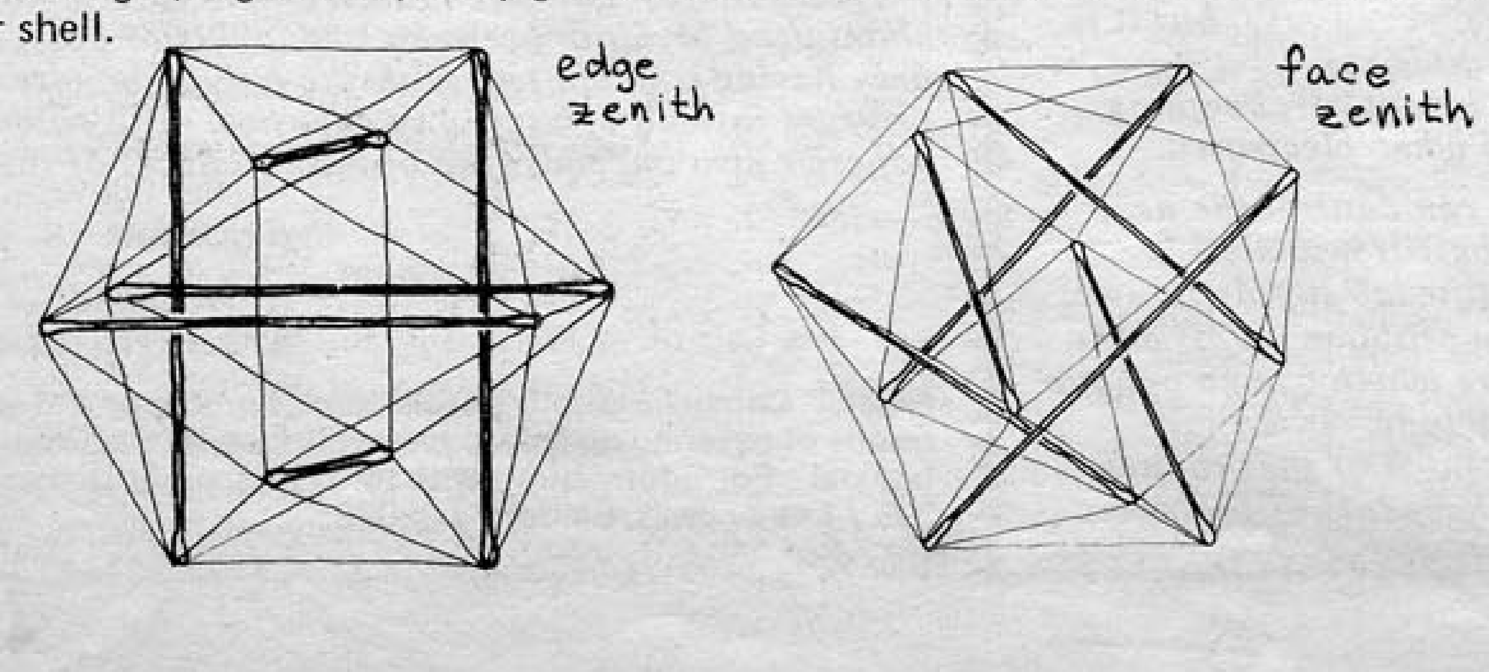
**Icosa tensegrity**

An icosa tensegrity can be built using pine logs, "captive columns", tubing strapped together, or stayed masts. For a 30 footer the dimensions of the compression members could be kept within graceful limits.

The simplest orientation is the edge zenith. There are two vertical members that would rest on foundations. The lowest horizontal member could be anchored at both ends with tension members or supported on secondary foundations. The floors would run across the different horizontal members and be suspended from the nearest icosa vertices.

Another orientation would be face zenith. Three compression members would rest on foundations. Floors would have to have their own framing system and be suspended from the vertices.

A light weight, higher frequency geodesic would tie into the icosa vertices to form the outer shell.

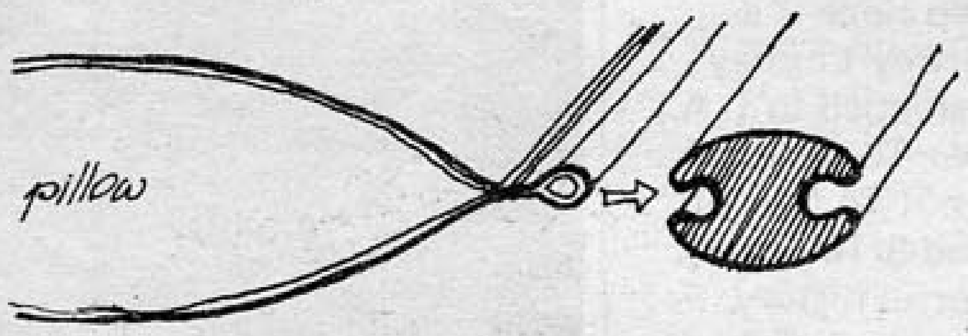


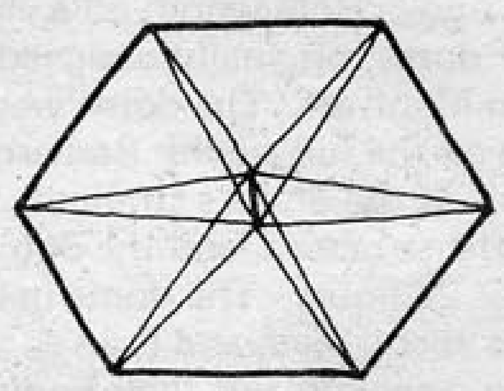

**Hex-pent dome**

In Tents (pp. 48-49) we talk about diamond breakdowns where the struts across the diamonds are replaced by cable—or where the cable is replaced with load carrying skin.

The hex-pent domes are built by replacing the interior struts of any hexagon with cable. A single cable harness can be used where the cables are in the plane of the hex or pent. Or a double harness can be used that has two cables running from each vertex to the opposite ends of a radial axle in the center—like a bicycle wheel. The harness can be tensioned by inserting the axle and then elongating it.

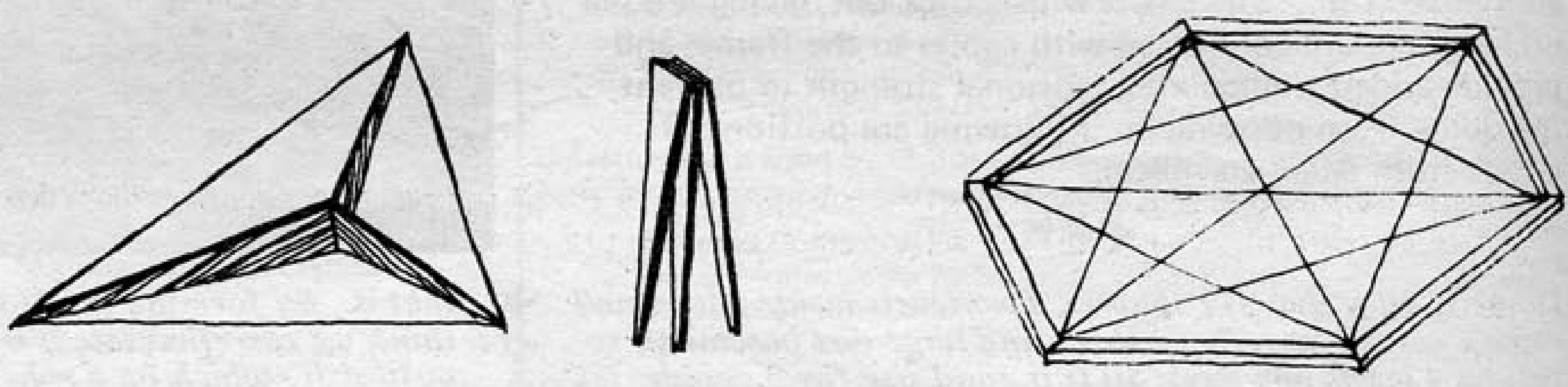
Instead of an axle, use a hexagonal pillow. The more you inflate the pillow the stiffer the dome gets. Build the tension harness right into the skin or use a material that doesn't need any extra reinforcing. The pillows could be attached to the struts by a tunnel and bolt-rope welded into the edges, the struts would be grooved. Assemble by sliding the struts onto the pillow, clipping the ends into a hub fitting.



**Internal struts**

The amount of material used in making struts can be reduced by having compression members run from the center of each triangle to the three vertices with a cable running around the perimeter. The struts can be hinged to fold up for transporting. I think that Fuller developed this idea several years ago, but I can't find the reference.



**Floors**

Small diameter floors can be made out of a tension membrane supported by a tension net like a tennis racket. A hexagonal floor can be made out of 6 compression members around the perimeter and cable running from the junctions. Planking can be laid on top of the cable or a skin stretched across.

A cheap insulated floor can be made by laminating ¼" plywood to both sides of urethane foam. You can pour your own foam for about 8¢ a sq ft but you have the problem of smoothing off the top surface. Use the plywood for the floor for the mold so the foam adheres, with wooden guides around the edges. Use a cross-cut saw to take off any excess. Then nail on another ¼" sheet of plywood.

**Space frames**

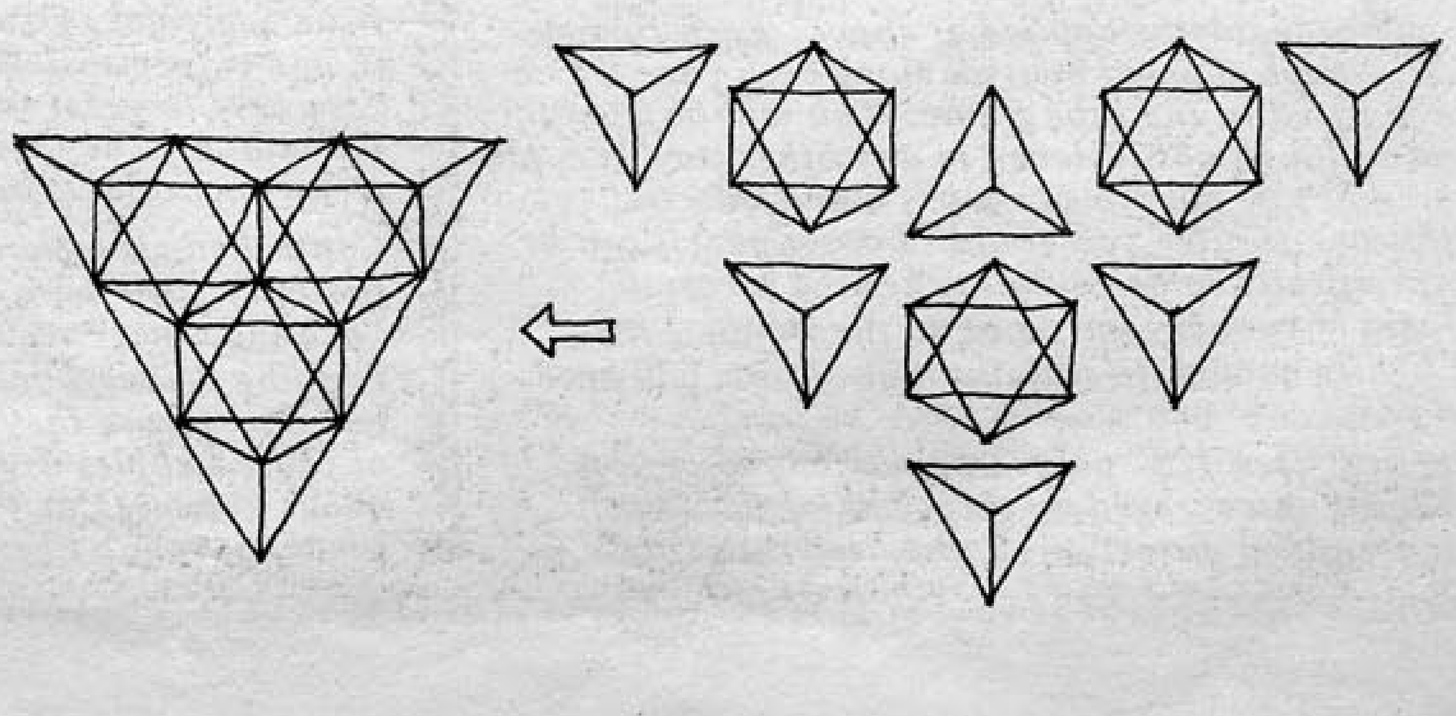
Space frames have been used on larger span and higher frequency domes and on smaller very lightweight domes. Space frames let you use smaller structural members without going to unreasonably high frequencies.

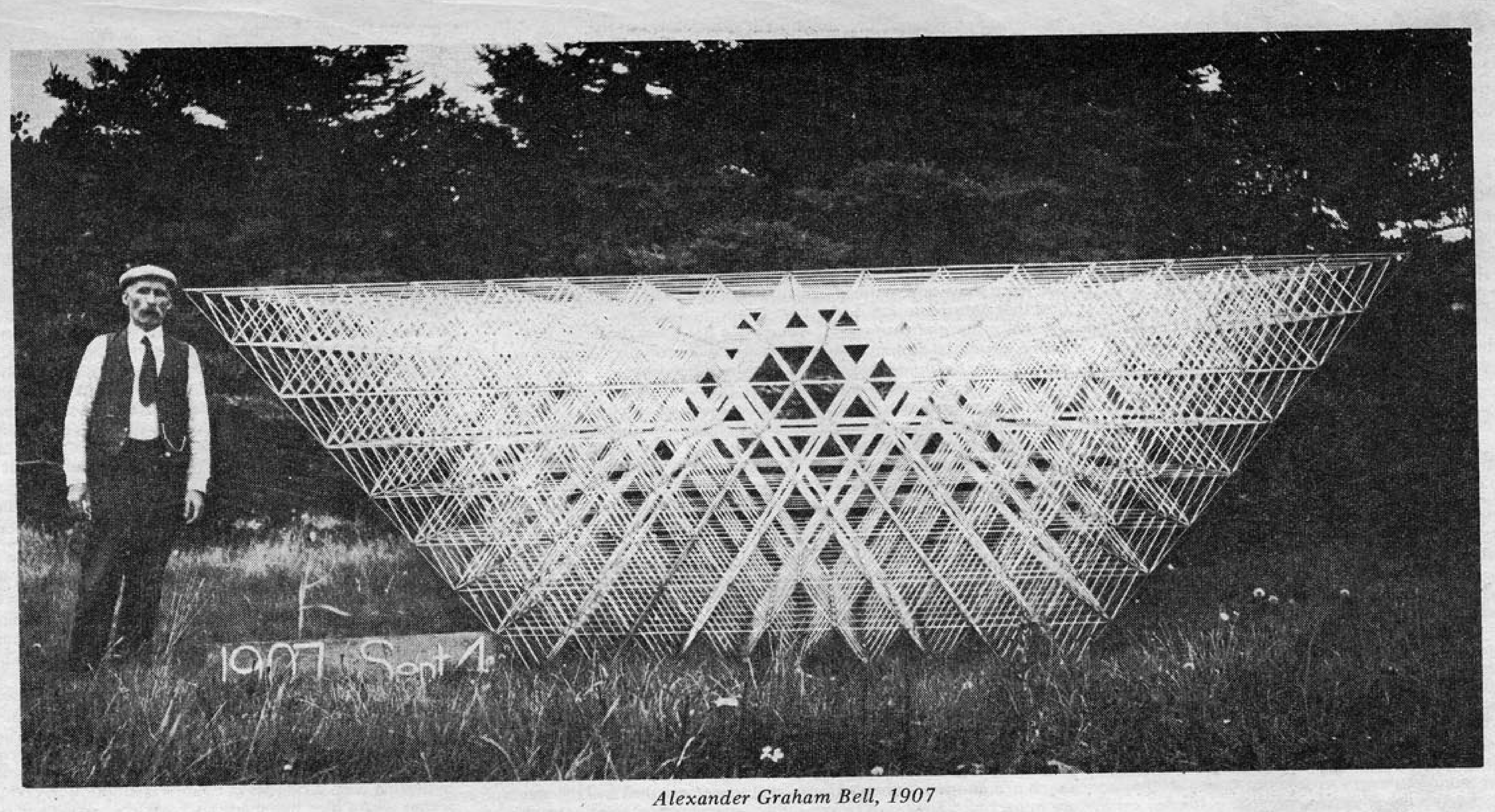
The strapped or washer hubs and 2 X 3 struts are 3" deep space frames with the hubs having to support torque loads. Torque loads are tension and compression acting together about a common point. Any member that has to support torque will be heavier than one that is only in tension or compression. Space frames come from trying to eliminate torque loads.

*Octet-truss*

The least redundant space frames are made out of the stable solids. The easiest to use are the tetrahedron and the octahedron. Octahedrons and tetrahedrons fill space—when octahedrons are close-packed the spaces left between them are tetrahedrons.

Fuller used a planar octet-truss made up of regular octahedrons and tetrahedrons to form the faces of the Ford Rotunda dome. Each face looked like this:

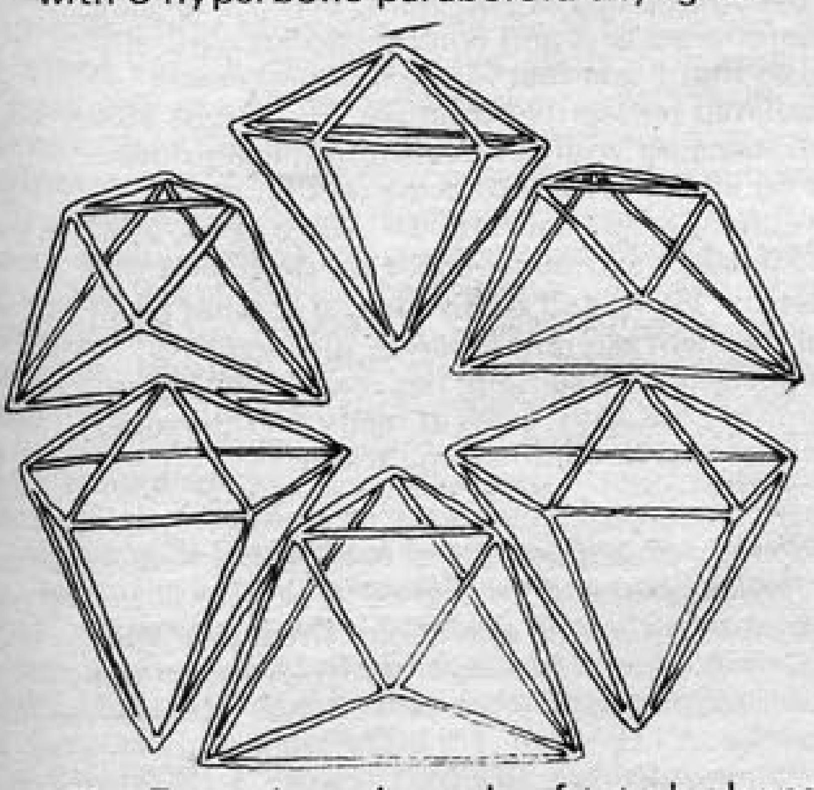


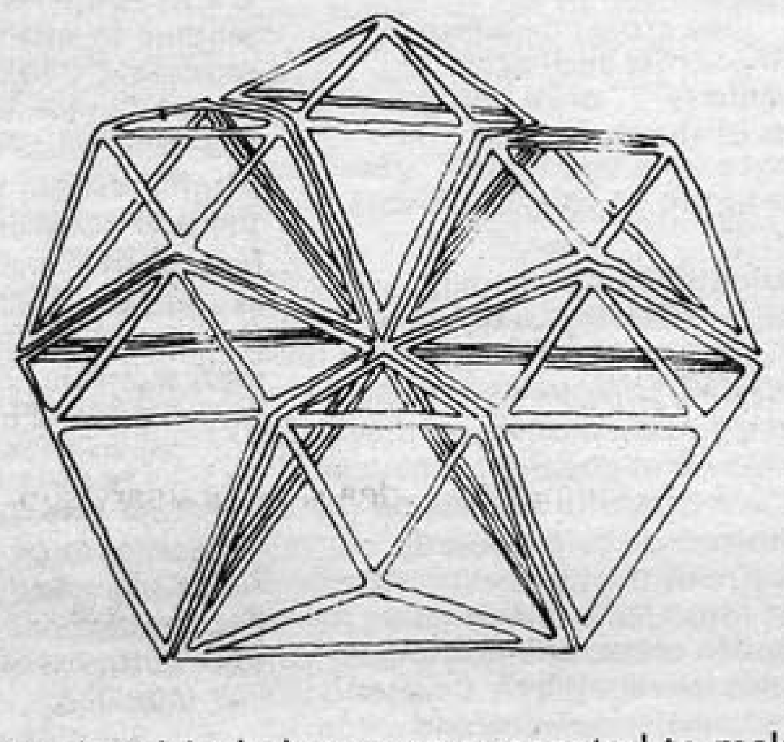



*Alexander Graham Bell, 1907*

Michael Ben-Eli has used irregular octahedrons to form the shell of a dome. It's a spherical octet-truss or two interconnected concentric geodesics.

*Octahedrons and tetrahedrons*
Geometrics Inc. built a dome that is made out of octahedron units that give a hexagonal pattern on the outside and a triangulated pattern on the inside. Each hexagon was fitted with 3 hyperbolic paraboloid skylights.

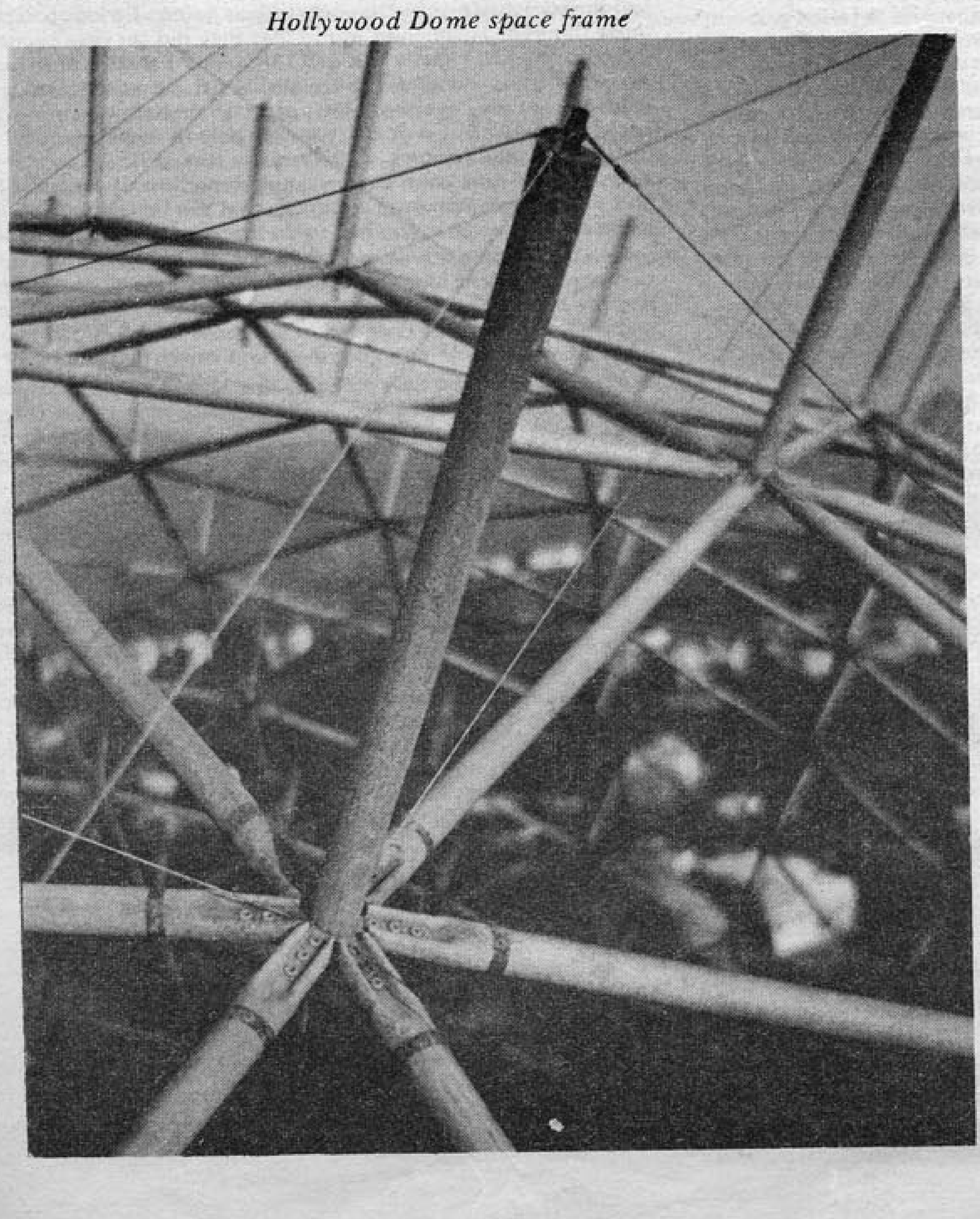




The Expo dome is made of tetrahedrons pointing in with their apexes connected to make a hexagonal grid. The hexagons were fitted with formed plexiglas panels.

*Hollywood Hills dome*
Each vertex of the dome is stabilized by 3 cables running to axial compression members protruding from adjacent hubs. Those hubs are in turn stabilized by cables running to the compression members of hubs around them. See p. 87.

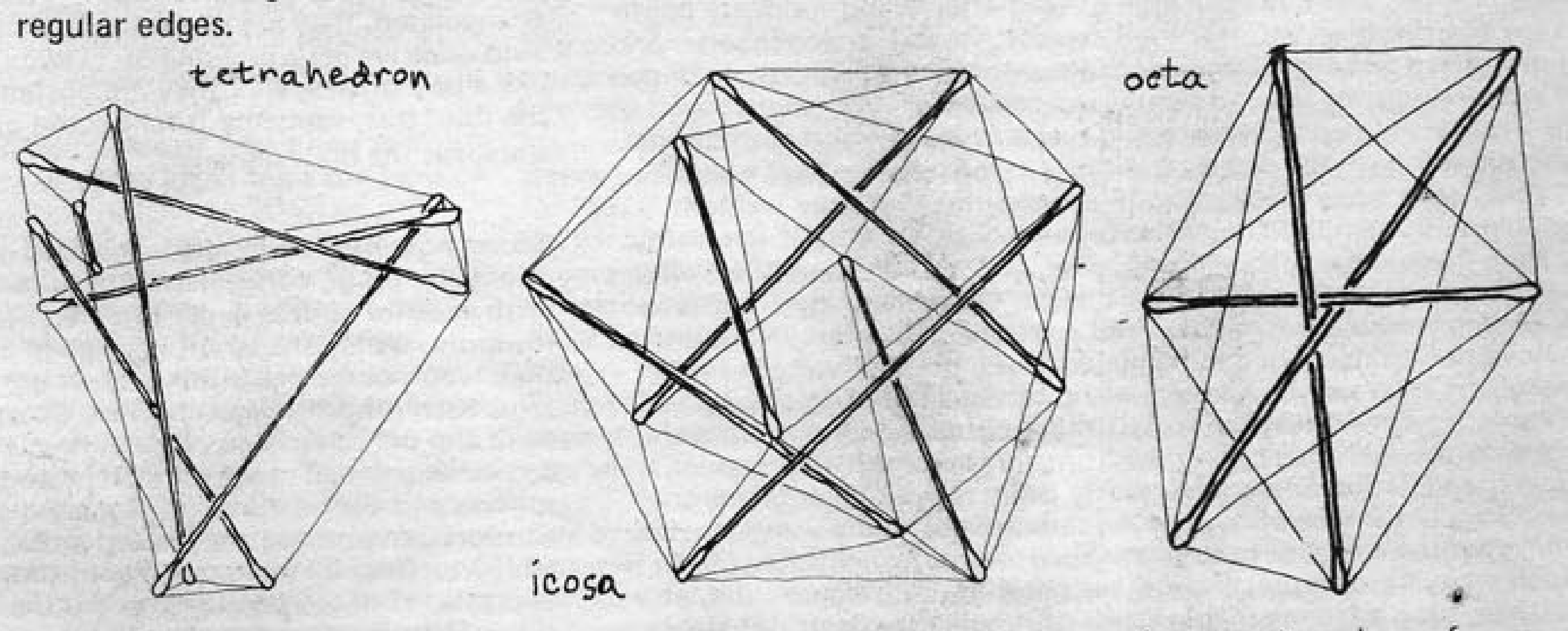
*Hollywood Dome space frame*



**Simple tensegrities**
The minimum structural system possible is a tetrahedron where each member must be able to be loaded in both tension and compression. Separating tension and compression results in the tensegrity tetrahedron—6 compression members and 18 segments of cable.

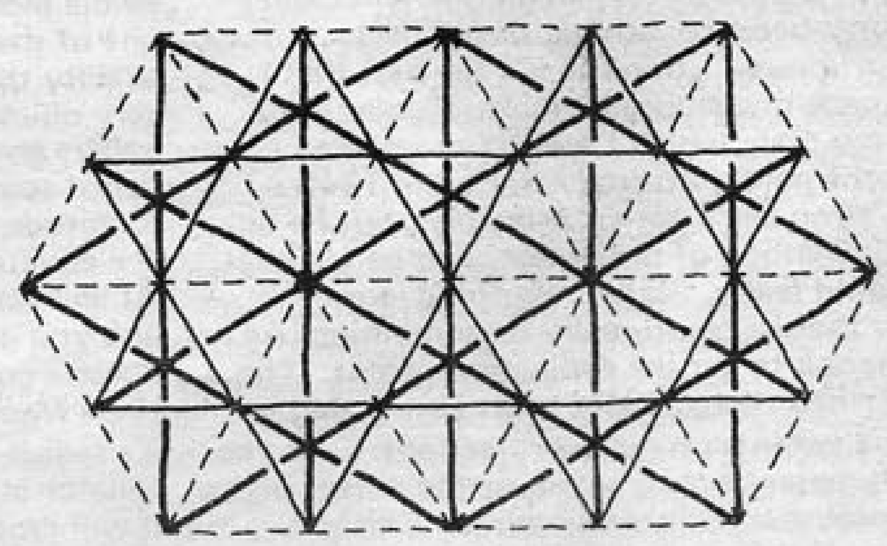
The octahedron tensegrity has 3 internal compression members running between opposite vertices. The normal edges of the octa are replaced with cable.

The icosa tensegrity has 6 internal members and 30 segments of cable replacing the regular edges.



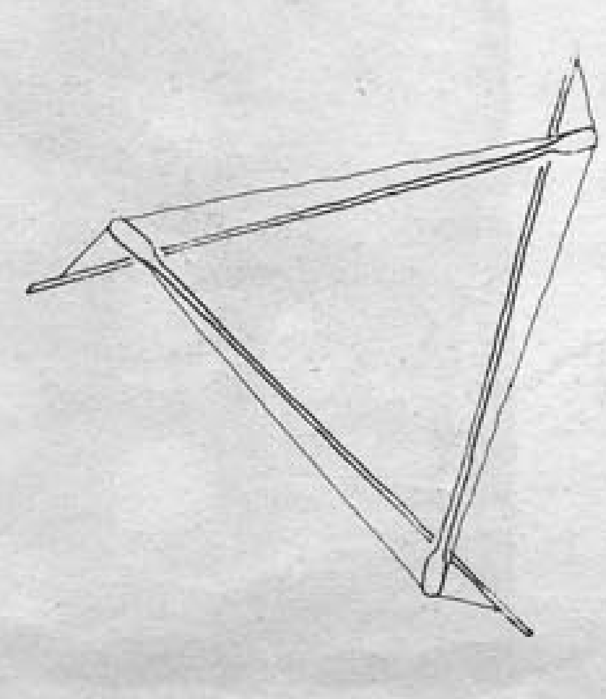

Models of any of these can be made by taping the compression members to the edges of the appropriate solids and then connecting the strings. When everything is tight, collapse the solid and remove it. Use a tetrahedron for the tetrahedron and a cube for the icosa and octahedron. See Hugh Kenner's model making instructions on p.94.

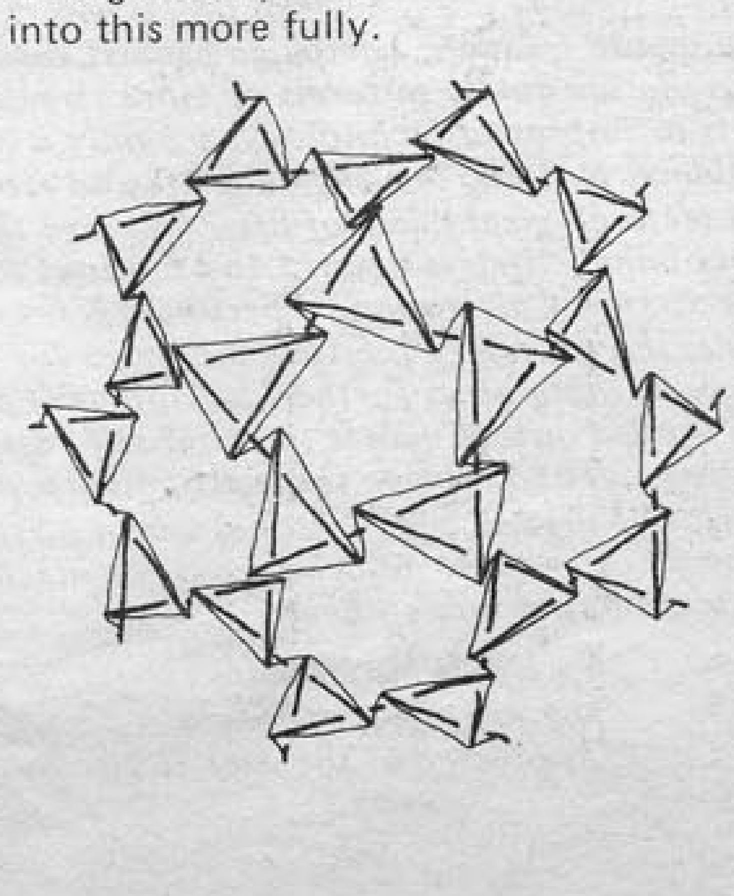
The octahedron is the easiest of the tensegrities to use. The Expo dome was originally going to be a space frame made of tensegrity octahedrons arranged like the octahedrons in the Geometrics dome above. The compression members of the octahedra oscillate from the inner surface to the outer surface in a 3-way wave pattern.



**Tensegrity domes**
The simplest tensegrity dome is an extension of the octahedron tensegrity space frame. Each triangle of the dome is one face of a octa tensegrity—the three members crossing are the three compression members of the octa. Six of the 12 cables of the octa become redundant and can be left off. Each compression member continues on to become a compression member of the adjacent octa face.

Any frequency dome can be built out of one length compression member and wire harness. Fuller's patent on tensegrity goes into this more fully.





# interview R Buckminster Fuller

In the past few years Buckminster Fuller has become increasingly well-known. He is about to make contact with a mass audience and Bucky Fuller may soon become a household word. America needs her saviours.

Many consider that Fuller's ideas hold the key to our survival on earth. Others abhor his confidence in technology and fear that if man follows his *design science* schemes he will find himself in a plastic/mechanical/soulless if efficient environment.

Since we have intersected Fuller's trajectory at various points we decided to ask him how he hit upon geodesics, and what he thought about people building their own shelters as opposed to mass production. Hans, who spent last summer with Fuller on his island, sailing and talking, conducted the following interview in L.A. in December 1970.

*The one thing that I don't know anything about and that has always been really intriguing is how you came about discovering geodesics and the great circle geometry.*

I'll tell you. . . I'll try to puzzle just how and where I first began to think things in a geodesic way. . . which means a total polyhedronal array, surface array. I'm sure it really starts with the fact that I not only wear glasses today, but I did have the four years without my glasses, the first four years of my life, and all I have to do to know what it is I saw before I saw is to take off my glasses, because the kind of corrections I have for those lenses are the same as I had when they first put them on me at four years of age. Without my glasses I cannot see human eyes, for instance, I can just see a little difference in color in the area where your eyes are, and it didn't occur to me there was anything else. I saw then only sort of blurry colors. There was nothing wrong with my color spectrum, so that I feel that up to four years of age my enjoyment of color was fantastically intense. I can remember talking to my mother about colors all the time. I think that what the kids get with psychedelics, — for instance, colors, — are no greater than I had by virtue of my lack of definition, which probably happens to them when they take psychedelics. At any rate, when I see lights at night with my glasses off, and they go into a whole cluster of very tiny little lights, I don't know if there is any way that you people who don't have eye trouble could see what I see. Possibly you may see it with raindrops on windshields, where lights break up into a myriad of little lights, but in the breaking up in those myriad(s) of little lights, they do so in rather beautiful circular arrays if you begin to study them. At any rate, I've seen these spherical arrays of light since I was born and lay in my bed thinking about them and their relationships with those points... and I've been able to see patterns and suddenly began to see triangulation very early. Secondly, when I first went to kindergarten and the kindergarten teacher had gotten a whole bunch of wooden toothpicks and semi-dried peas which you could stick the toothpicks into and you could make structures and the children who did not have the glasses trouble — eye trouble — that I had, all made structures that looked like structures that they were familiar with. And so they were familiar with rectalinear structures, so they made cubicle things and so forth. I couldn't really see what the other ones made without my glasses, but I made my structures by feeling, and by putting peas and toothpicks together I found that they were unstable when making necklaces. But when I got to the triangle, it was. . . it had a form-of rigidity. so I tried finally making a teepee, like an Indian teepee with three of them coming from a triangular base. I made a tetrahedron and then I went on making more triangulation and inadvertently came to making octahedrons too. So. . . I can remember the kindergarten teachers — my teacher calling another teacher to look at this structure which I had made, which was very different from the other kids'. . . because I did, at the time, have a feeling in my hands of it being stable or not stable. So this got me into triangulation very very early. So I really had an advantage over other children who had preconceptions by virtue of the forms that are in their environment, which I didn't see — didn't feel that way. I'll simply say this was the earliest part of my background of my thinking about omnidirectional enclosures that had some structural relationships, in that I found that triangles worked better than others. . . so I kept looking for the omnitriangulation of points that would give me such enclosures. And having seen eagle star points in the sky, I'm sure I began to look at the mathematics. . . By the time I then did have my glasses, did go through kindergarten, did go through elementary school and got to my geometry, and so forth, I always got A's in mathematics and physics and biology and so forth because, I think, of my deep interest in mathematics and structure. I think that's the best that I can give you. I know that I made my geodesic omnitriangular grid, the 3-way triangular grid for my map, which I was able to patent — I got my patent in 1943, but the patent attorney started in 1940 — he thought the best way to. . . you can't patent principles, but he felt you probably could patent the method of projection, and he felt that would be the only thing he could really. . . the only thing in my energetic-synergetic geometry that he could really do something like a patent on. And so he undertook to get the projection patent. The head of the patent office had ruled categorically years earlier that it would be impossible to get any patents on math projections. . . but he did succeed in getting the only patent ever granted, at the patent office, on a method of projection, because it really was a novelty, alright. And now, in doing that I found this 3-way grid. I found to my amazement mathematicians making statements that you could not make 3-way grids of great circles. . . and they didn't realize that they could come and go and come and go as they go around. At any rate, I did find them, and it was, incidentally, the chief cartographer at American Geographical Society who said to Time, Inc. . . . when Life magazine was interested in publishing my map, and did publish it in 1943, they made enquiry of a number of well-known cartographers regarding my method of projection and the cartographers said in scorn, "It is pure invention; it does not conform with any of the known ways of projection, and therefore, it's just some kind of fudging — it's not good cartography, not good geognosy, not good mathematics.". . . That these three great experts — one was the chief cartographer for the State Department of the United States, Dr. Boggs, and the other head of the American Geographical Society, and I've forgotten who the third one was, but they all three made the same statement — they all said "pure invention" and my patent attorney then used this statement of disdain very effectively in getting the patent granted at the patent office. Now, they also said that it was impossible to make any 3-way grids of great circles, and you think about that, of course you think you've got a little local one here — they repeat themselves in various ways which you learn more and more as you get into my work. . . and so I did find that nature is using 3-way triangulation. This gave me, then, the realization that whereas. . . you take a flat piece of paper, it has no structural strength whatsoever — it will crumple. But if I make it into a cylinder, a simple curvature, I can now use it as a column. . . that is where all the lines are parallel to each other like a barrel, but I saw that if I could make a 3-way interaction of great circles, it would give me extraordinary stability. And that is really what compound curvature is. These are things I went into very deeply long ago and I just simply say that they were. . . Certainly all through the Thirties I was very aware of my 3-way great circling and then brought it to culmination by the publication, as the map, in Life in 1943. . . I give the explanation of the barrel. In a barrel, you'll have a number of staves parallel to one another. Those staves make a cross cut through the barrel. You'll find each of those staves looks like a keystone in an arch. Each stave is a truncated section of a triangle whose interior apex would be at the center of the barrel. So you just cut the beautiful triangular wedges, but you cut off the inner part which isn't necessary. You still have a wedge where the outer part of it is a greater chord than the inner part. Therefore, it can't fall in between the others. So all these staves are in line and parallel to one another, bound in a circle. . .there are comprehensive tension straps to hold them inwardly. They can't move outwardly due to the finiteness of the straps coming back upon themselves, and they can't fall inwardly on each other because their external chords are bigger than their internal. So the barrel seems to be pretty stable, but the tension bands don't touch one another — they're in parallel to one another and the staves are in parallel. They don't cross or give you any triangulation whatsoever. In fact, they let infinity into the system because the staves go on and on to infinity. So you take a blowtorch and burn out one of the wooden staves of the barrel and the whole thing collapses because that leaves enough room so that the outer part can fall in through the smaller inner part, because what the blowtorch does is let infinity into the system. . . or the nothingness of the universe gets into the system. Let me now make a wooden geodesic sphere in which each of the triangular facets are external faces of a tetrahedra whose interior apex will be at the center of the sphere, and I'm going to truncate those, so I will now see really a wooden barrel — a spherical barrel, and it has tension straps. . . But its tension straps are triangulated, they are not just in parallel. . . they cross one another. And once we get a crossing of. . .two lines that cross each other like a pair of shears. . . they are unstable angularly. . . once you get the third one, suddenly it takes hold of ends of the shears and stabilizes the opposite angle.

So we now have an omnitriangulated geodesic sphere of wooden triangular plugs, corks, each one pressed against the other one, each with exterior chords larger than its interior chords and they can't fall inwardly. When the straps have great circles going completely around they won't come off and the straps are fastened to each other, as they cross each other. Therefore, they hold themselves in position. They can't slip off the sphere. Everything is held as a beautiful harness on the omnitriangulated. . . Great circles are the shortest distance around spheres and they are intertriangulated so they're in the most comfortable position they could possibly get into. Now let me take a blowtorch and I burn out one of those wooden corks, and nothing happens. It doesn't collapse as did the wooden barrel. Why? Because it leaves an opening there, alright, but it's a triangular opening and a triangular opening is a stable opening. If I burn out four of these adjacent to each other and make a larger triangle it still is a triangle and it continually frames the opening with a great circle. Hence, she will not collapse. In fact, I burn out very large amounts without the thing collapsing. . . This suddenly gave me the fantastic realization of the fundamentals. . . This is really the fundamental of compound curvature. . . is this 3-wayness of finiteness crossing itself up and it all being most economical. Great circles are then the most economical distance between points on spheres, as against the expression that a straight line is the shortest distance between two points. You find there are no straight lines in the universe. The whole universe is all motions of curvature, so we are interested in one of the most economical curvatures. . . and great circles are just exactly that which we call geodesics. You can prove that to yourself very quickly by thinking about the great circle as a line formed on a sphere by a plane going through the center of the sphere. The equator is just such. All the meridians of longitude are just such. Meridians of longitude go through the axis which you spin the earth on, by which the equator is generated, so they are inherently at 90 degrees to it. At any rate, I want you to think of going to 80 degrees north latitude, and you get a very much smaller circle. It cuts through the axis but doesn't go through the center of the sphere. So I'll take that little circle from up there and you just take your dividers, and get whatever it's radius is, and bring your dividers down and put one end on the equator and strike a lesser circle of 80 degrees north latitude for size. It will cross the equator at two points, a and b, so this little circle crossing this main big line of the equator. . . quite clearly it's a shorter distance between a and b on the equator than going on the lesser circle, where you go and detour off and then back on the main sphere. In fact, it's very easy to prove that it is the diameter of that circle. . . is much shorter than the perimeter. Now great circles, being the most economical distance between points on spheres, and being omnitriangulated, and triangles being non-distortable, you can understand how I began to feel very powerfully the way in which geodesics really do work. Furthermore, I've considered a great deal about footballs and balls and pneumatics from being a little kid. And I saw that as I pumped up my basketball or football, it went from supine. . . flat, into this beautiful firm condition. But this is because the molecules of gas were trying to get out of the system. And they got hot because they were in such action. The kinetics of gas are something easy for the brain to understand and feel. . . the action of those individual molecules of gas. I saw all the molecules of gas were trying to get out of the system — that gives it the high pressure — and they were stretching it outwardly, and so, therefore, the skin is designed to go the other way, holding it inwardly so that the skin is finite and comes back upon itself. And it represents a tensional force with the arrows bound inwardly, balancing all the molecules, bouncing, hitting it, caroming around and every action having its reaction. So I began to see that it would be possible that geodesics could be similar to what could be called discontinuous compression/continuous tension, where every molecule has to have one it pushes from, like two swimmers in the middle of a tank. When you are swimming you dive from one end of the tank — gives you a little acceleration into the tank — when you get to the end, you can put your feet up and double your body up and so forth and shove off from the tank, and if two swimmers could meet in the middle of the tank and double their bodies up like that and put the soles of their feet together and thrust and go in opposite directions, I saw that the molecules that are in motion. . . and every action has its reaction. ... there has to be some reaction set, so each molecule which is caroming around, circularly hitting glancing blows and then making a chord, then another glancing blow, had to have one it shoved off from. Each one would have to be balanced, so a balanced pair. . . all the forces are caroming around. . . each one will represent one of the chords, the compression chords, which the two ends pressing outwardly glancing blows against the tension skin, which are trying to pull inwardly and they are pulling outwardly. So there's a net arrow outwardly in the middle of that chord against the net of arrows pointing inwardly. So. . . I saw this represents what the gasses are doing and you could make discontinuous compression/continuous tension geodesic structures in this way. So all this came in as a fundamental feeling that in dealing with geodesics in counterdistinction to compressional arches where men had made lesser rings of stone and bricks and so forth, like Santa Sophia, fitting them beautifully and very mathematically, one to the other, so they wouldn't fall in, and taking and putting chain around the bottom of the dome to take care of the thrust of the enormous weights of the buildings, they could build a dome that would not thrust outwardly at the base and allow it to collapse.

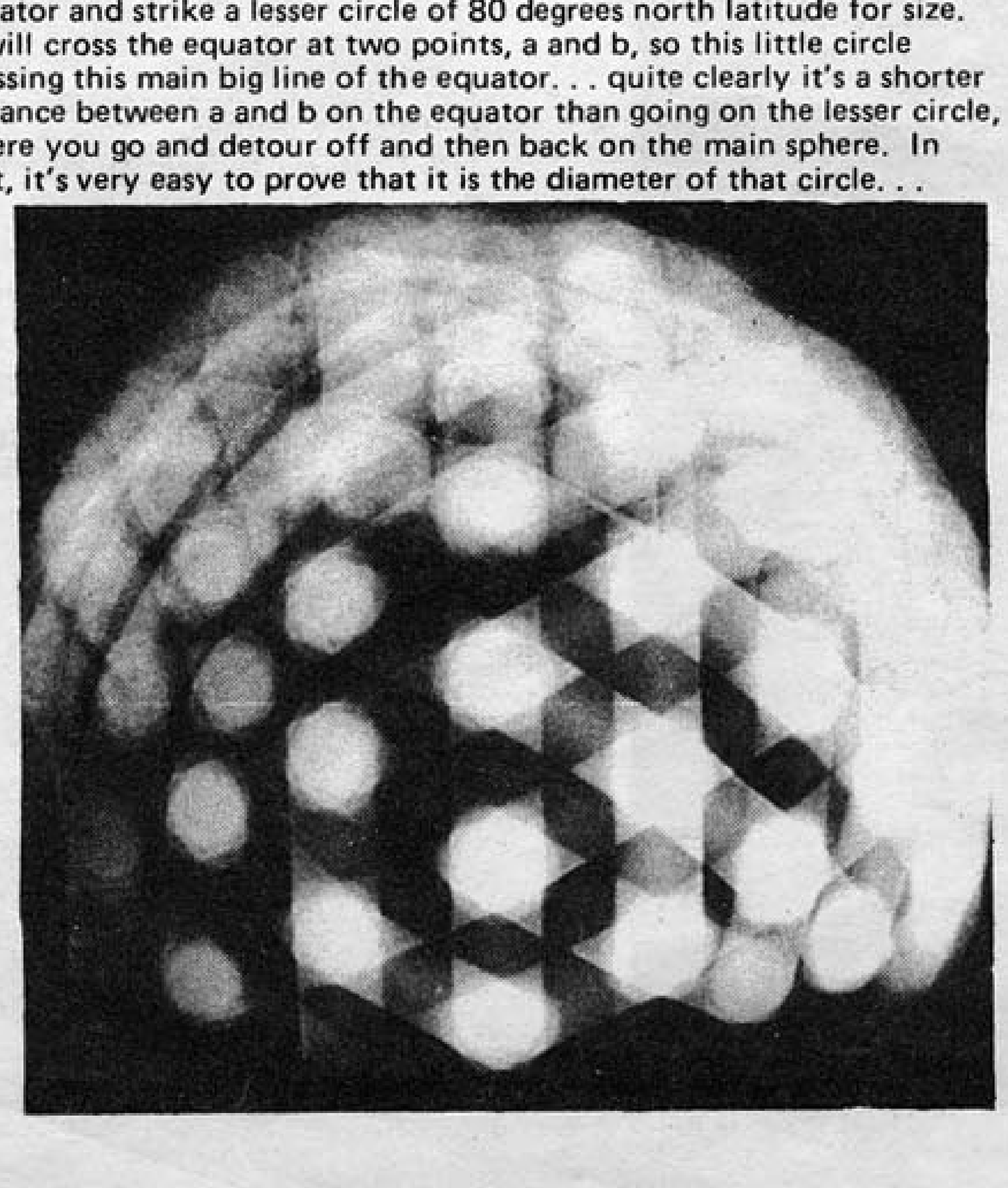
But I saw that men are very limited in the use of such domes. In fact, St. Peter's is the biggest they've ever built — that is a hundred and forty-five feet in diameter — and I saw that in tension there is no limit — you can make as big a pneumatic bag as you want, because tension is always operating toward larger arcs and compression is naturally tending to smaller arcs, so that I saw that in the comprehensive geodesically omnitriangulated tensegrity structure, I would be able to go to unlimited spans, because your only limitation is tension. I've found that there is no inherent limit of cross section due to length. We get to where there is no cross section visible at all, as in the pull between the earth and the moon. These are principles that have been in me very deeply, Hans, and I don't know at what point as a kid you really separate them out and describe the beautiful things, but the intuitive feelings, the sensing, has really been there right from the very beginning. Always, I could really feel the apple in those terms of hydraulics and doing the same tricks.

*Where do you think geodesics are going to move from here? Right now they seem to be in places like Expo and the Climatron and very special functions. And then we've seen them in places like Drop City and Pacific High School and again, special places, and then just beginning to get into more common use through Temcor and bigger companies, like that.*

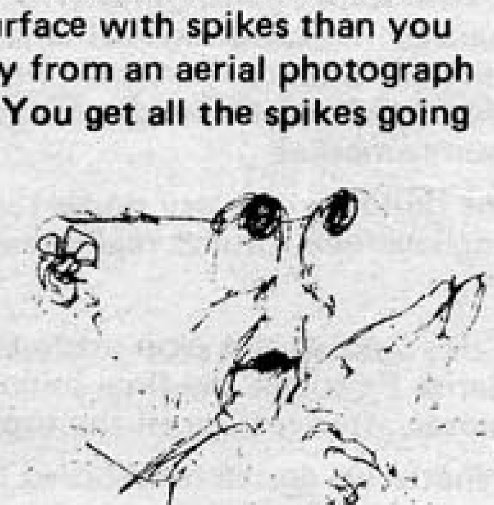
Well, there are two very obvious big trends. One is that I have found a system which, as an individual, I can go off to Bear Island and just take the young spruce saplings and I have had such experience with geodesics that I could take those short little saplings and produce a beautiful geodesic truss dome of various sizes. And I saw then that this was something an individual going back to the art of the indian and doing things very neatly and doing proper tieing. . . that the Oriental proclivity for tieing bamboo properly and so forth made me feel that Orientals would like what I was doing. I tried to explain those things in Japan and I found that they did get very excited. . . they did feel just exactly the way I thought. I tried it in Africa at the universities and all across equatorial Africa, and I found that the students got very excited. Rafia palm is fantastically strong and approximately no cost at all. We were able to make beautiful 50-foot diameter geodesic domes — 2000 square feet of floor space — for $10 worth of rafia palm and investing some time of the individual. So I saw that mathematics are things that can be learned and in order to do a good geodesic you had to do mathematics. Some books were involved and some literacy was involved. There was a little difference between the naked illiterate native and what I could do with my head and my hands. But I didn't need any really fancy tools — a good knife and that was about all I needed to cut those things. I had to know what length I was going to cut them and where I was going to tie them together. I really did have to know that and I saw that was a whole complete discreet difference. And I saw that once someone had seen one of my geodesic domes they could. . . for instance they could make a mound of earth and they could put the sticks on the outside and tie them in place, remove the earth afterwards, get it empirically. A great many kids have done things empirically with what I have. They have been very ingenious in all kinds of ways approximating the actual discreet measurements that were made. But if you know my work, then you know. . . that I am able to actually do mathematics that we know within. . . figures that we can't lay out on wood. I can make them to thousandths and ten-thousandths of an inch — great accuracy. I've learned the more accurate they are, the firmer, more satisfactory they are every time. So I do try to go to some extent in teaching the Africans and others the spherical trigonometry. Well, I've found that is something that can be taught in one week. You do have to go back to certain things. You have to go back to having some tables of functions. You do have to know your spherical trigonometry. You have to have learned the simplest way of remembering spherical trigonometry. I teach it all on one page as far as fundamental principles go. And I have been very successful in doing that. . . So. . . there are then two outlets:

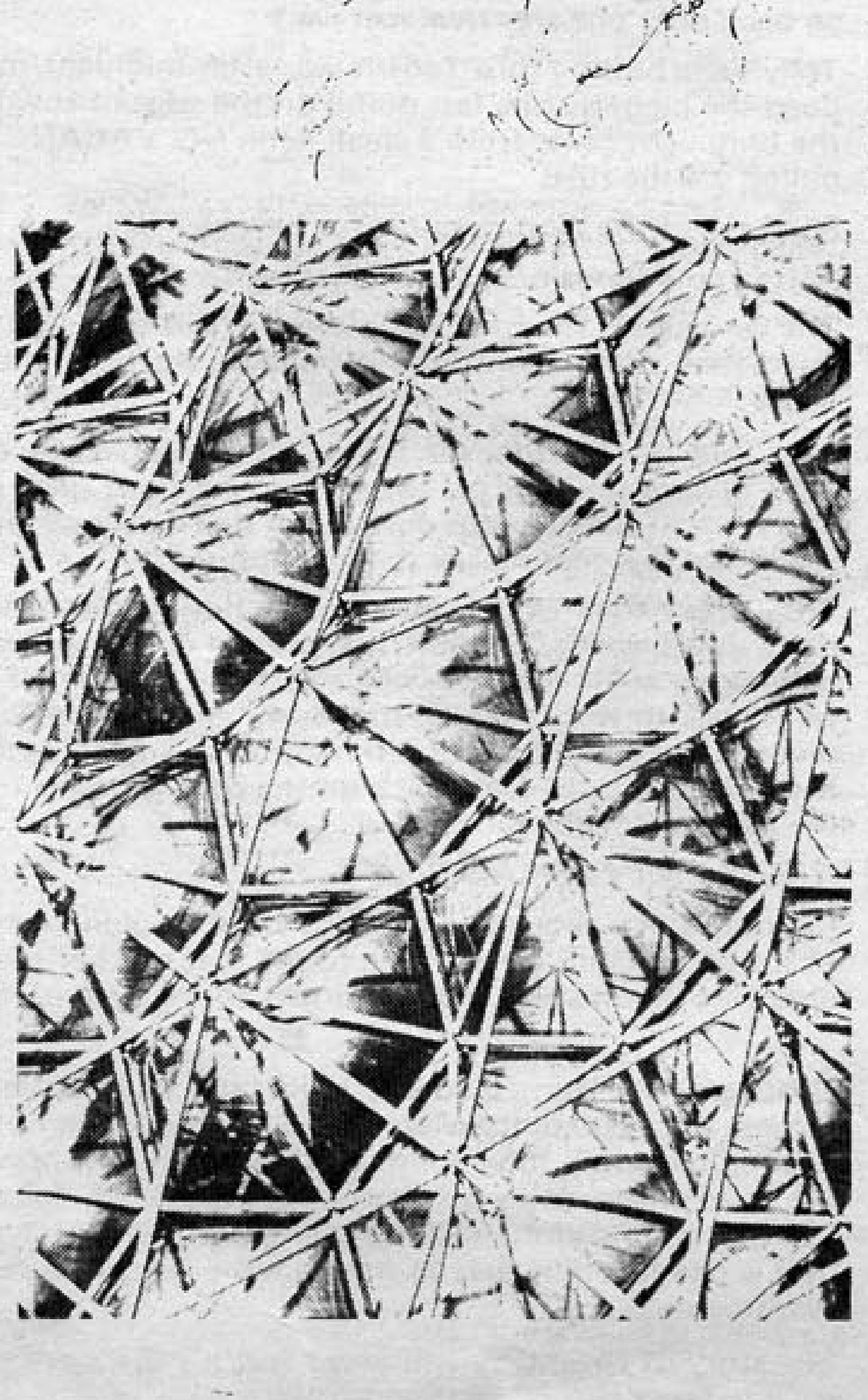
*Reformers who would treat the campaign against environmental and human degradation solely in terms of more strenuous scientific efforts or improved technology, see only a small part of the problem. Nothing less than a profound reorientation of our vaunted technological "way of life" will save this planet from becoming a lifeless desert. And without such a wide-ranging preliminary alteration of personal desires. habits and ideals, the necessary physical measures for mankind's protection-to say nothing of its further development-cannot conceivably be carried out. If man is to avoid self-extinction, he will consciously have to replace the mechanical world picture with a more inclusive organic and personal world picture. The God who saves us will not descend from the machine; he will arise once more in the human heart.*

*By Lewis Mumford*
*The Pentagon of Power*
*as printed in the Oct 31'70 New Yorker*



the way you take the individual who is literate and show him that, by guarding the books and tables, that he has that much. . . a few pencils and this and that and some paper to make some calculations—somewhere he can scratch. . . he can really be an outcast on an island and build some pretty substantial structures. . . be extremely useful to him and be very very pleasant because you get into quite large space controls, absolutely free clear span space control. Incidentally, in that respect, I saw that nature across in the tropics can get into all sorts of vines. It's perfectly possible to design geodesic domes with what I'll just call a trellis, a triangular trellis, that is too light for you to climb on and so forth, but plant your vines on it. . . then the vines themselves begin to bind up, and because these are the shortest lines, the vines tend to follow them. They will fortify every line in the geodesic dome, and the dome will simply grow and get stronger year after year, be bound to earth and become a very extraordinary kind of forest bower. I found this very appealing to a great many people around the world. I've tried the Orient, I tried Africa, everywhere I've gone, and been able to infect the natives with great enthusiasm for it. They did have to have a minimum of learning. . . appetite for learning that is something they never had before. . . which is also very exciting. You realize it was in that truth. . . the realization that you could have a higher advantage over nature by just a little of that kind of learning, that was something that I was able to get them to understand: the feeling of mastering mathematics is a very great thing for the confidence of human beings. . . So this is one great outlet for geodesics. On the other hand, it was perfectly clear, as I did in my first big geodesic dome for the Ford Motor Company. . . I was able to produce the geodesic dome, reduce its weight to one-half what it would have been. . . It was produced on class A tools where we were able to hold the positioning of the rivet holes. . . the diameters of the holes themselves, and so forth, we were able to hold these to a thousandth's inch accuracy, with the result that the dome was exactly one-half the weight with equal strength. . . half the weight it would have been if the work had been laid out by the best sheet metal workers in history with their naked eye. The dimensioning was done through the lathe, through the indexing on the lathe. You get twice the strength by simply getting into control of dimensions below where the human eye can lay out. That you get two domes for one is in itself a very astounding matter. So I saw, then, you could go so far with the individual and what he could do in the forest — he could get great advantage he never had before. If industry really took this on with the very highest capability of technology. . . if industry was to take it on, there are things that we could do in geodesic domes that are spectacular. I haven't let much of it be visible except that anyone looking at the geodesic dome in Montreal saw a very beautiful piece of mechanics. It did all kinds of things to your intuition. You saw there were curtains that could articulate. . . and they could articulate completely by photosynthesis and so forth. . . could let light in and out. . . it's possible, as our own human skin, all of our pores, all of the cells organize. so that some are photosensitive and some are sound-sensitive, and they're heat sensitive, and it would be perfectly possible to create a geodesic of a very high frequency where each of these pores could be circular tangencies of the same size. One could be a screen, others breathing air, others letting light in, and the whole thing could articulate just as sensitively as a human being's skin. And I really think geodesic domes such as that really will be developed. I've gotten into the realization that it is perfectly possible to do them without any leaking kind of problems. There is an automatic — particularly as you get into the tensegrity — there is a spillway system where water just never can fall in, yet lets all the air through that you like. That shows clearly in my patent on the tensegrity. That needs to be done in polyester fiberglass. I haven't gotten companies who have the tools and the capability, the mathematical capability and so forth. . . really the aerospace technology. . . have not been free, the way our economies work around the world so far — and it's not American economy; they're all the same -- fixation on armament. . . I can convert that kind of capability to making these very extraordinary kinds of geodesic domes. . . the kind of problems we have of just the heating, and talking about the energy needed for New York City today. . . they keep having energy shortages, they keep putting on more and more electrical tools. . . surely it's very desirable to be cool and warm at the right time, and all those things are perfectly o.k. as far as I'm concerned, but nobody is looking at New York in terms of architecture as being energy conservation. . . a simple phrase. But it is exactly that. If you want to have a good air-cooled engine, you put fins on it. You get cooling by having wire and metal heat transfer. There are more atoms to conduct the heat away from the source of concentration and get it distributed to air molecules on the outside. So you put fins on to have a good air-cooled motorcycle engine, but you can make an even better one if you have spikes, that is, you get more surface with spikes than you can with fins. If you look at New York city from an aerial photograph it is the most beautiful air-cooled engine. You get all the spikes going





into the air, generate all the energy for those things and get rid of it just as fast as possible through those walls. And I found then, something else, that if we get into unitary enclosure, a single envelope system. . . When we double the size of geometrical object, we increase its surface by 4. The linear goes to 2 — from 1 to 2, and the surface is $2^2$ or 4, its volume at $2^3$, which is 8. Every time I double. . . remember you get the same . . . it doesn't make any difference whether its a cube or a sphere that we're talking about. . . Now it does make a difference as an enclosure — the sphere encloses the most volume with the least surface of any geometrical object. A cube is really quite offensive in the amount of surface it has to have for a given amount of volume. And so every time I double a spherical structure, geodesic remember. . . I've already given you the great strength in compound curvature. The compound curvature with a sphere. . . the sphere gives you most volume with the least surface. So you have two completely important reasons for using it, and every time I double the size of the geodesic dome, the amount of surface is only four and it's volume is eight. So every time I double the size of a geodesic dome, I get eight times as many molecules of gas inside, or atmosphere inside, and I only have four times as much surface. So every time I double, I halve the amount of surface through which a given interior molecule of gas could gain or lose heat. So when I get into something as big as covering New York City, I found that it is extraordinary — the economy that comes. I get to where the geodesic dome covering mid-Manhattan of two miles in diameter. . . I found that the surface of that dome was only one-eightieth the surface of the buildings that stood below it. One-eightieth. . . which means that I would be reducing it's heat losses by eighty times by having a cowling such as that. Furthermore, we found that with big cowlings, the number of the interior molecules involved is so great and the amount of surface so negligible that it would be so stable that you would be able to keep it really whatever level tropical temperature you would like. It would hold that year in and year out without any. . . whether its cold or heat. So that the amounts of energy being poured into that city to try to get it to the special condition of humanity — instead of doubling the energy input as they would like to do. Today, I can reduce the energy take eighty-fold and give them all the same results they got simply by getting a geodesic dome over the top — just think of the difference. These are the things I find that society is not yet well enough acquainted with. So somewhere in between the idea of all the little individuals going off and doing what they are doing today, and proliferating the use of geodesic domes — getting their own feeling about it. . . the kind of statements I'm making are going to get to be popularly understood. In other words, this can be the basis of the democratic thinking, and the democratic thinking will be properly informed regarding energy, energy as structure, energy as irradiation, energy, then, as heat and the conservation and regeneration of life. . . and the use of the structure to give you the environmental controls and the kind of economies I just spoke about, where there's no reason. . . there's nothing the matter with a high standard of living. Nobody ought to resent a high standard of living. It's simply a matter of everything being done in a very wasteful way. Then there's a fundamental sense of resentment that it's being done at the expense of others, and this need not be. All these high standards can be accomplished for everybody. In fact, I just gave you a way in which we can practically eighty-fold the the number of people we could take care of in very high standards of living.

*MM hmm. Yeah, there were several things — one of which was seeing many kids wanting to be out in the country and away from the kind of things. . .*

Well, let me talk about that. There is a tendency in society to think of what it's doing at any one time as being permament. So there's this going off in the country. Yes, human beings go off in the country; you and I have been in the country, very deeply and stayed there for a long time, but we've done it many many times, haven't we? In other words, you can do things very intensely, completely, and yet life changes, so at another time you're doing something else. You're very deeply deployed away from man out in the middle of that ocean where you've been as an ocean-racing sailor. And then suddenly you're intense, right in the center of Los Angeles or in the center of New York. . . with very good reasons. I find our society simply is increasing its range and frequency of going and the world gets to be everybody's backyard. Nobody's leaving home — it's just that you cover more territory. There are times when we converge to do what you and I are doing this very minute — a metaphysical exchange where we're banding something together that's absolutely weightless. . . But what is most important of all, really, this understanding of the mind. . . And then we deploy and having our physical experiment out in that boat in the middle of the ocean, and not many words are being said, and you're getting fantastic experiences with nature — so in the same way kids are going to be living off in the forest, and in many different ways building their geodesics. Maybe live off there for six months, be off for three years, and there will be times when they're going to be coming together again. I find some kids migrating from those very places will come and hear me speak at this place and that. So you converge for the metaphysical and you deploy for the physical. That's man's pattern. And this is a great oscillating phenomenon, a pulsating phenomenon. So the great highways are people converging and then diverging. . . the holidays — enormous pulsations — are very very exciting things of man getting around. . . beginning to pulse over the whole earth. You'll find change. . . we'll pulse into larger parts of universe.

*Do you think, then, the high density living, like the East St. Louis Project is going to become more and more important? (The East St. Louis Project is a proposed 750-foot (?) dome that will house several thousand people.)*

I think there are very important transitional sort of things going on. Man really was a farmer yesterday, and he was really locked out in the country, and he stayed there for thousands of years. .knew nothing else. . . and he was isolated from his fellow men and he was a peon, and really a prisoner because of his ignorance of where he was in isolation from his fellow man. So all that is over. The farming is being handled much better mechanically, there are no jobs for people to find, so they went temporarily to the city. The city is really sort of. . . a temporary converging and looking for the next orientation. So then the same kids will go to another city for awhile, and then they'll get off to a commune, off into the country. It's a springboard for a new kind of life, and gradually means as more competence of all of humanity develops, you'll have more of humanity enjoying total earth, as I say. . . It's not going to be just everybody out as a traveler continually, not that kind of nonsense, but people will be going. . . are going to spend three years in Katmandu, for what good reason, for whatever it is, etc. . . So they'll be moving — this man will be moving — there will be enormous combinations of motions. In Katmandu you're going to converge from time to time into Calcutta or into Peking or wherever it is.

*Then it seems to be important right now for kids to be moving off into the land and providing their own shelters, and so, in that, the physical is decentralized. . .*

In being forced more or less into the city — that's the only place where their total needs could be coped with and where there is an information system that you begin to find out where you could go and what needs to happen next. . . Babies being born in very unnatural ways. . . I don't mean born unnaturally, but being reared in unnatural ways. They have to be on the street, they like to have the feeling of play and then they've got to play baseball with automobiles going by. Nothing could be more illogical. So there's a deep hunger of those kids who have been born in the city, to feel something they've never seen or felt before. . . intimacy with the trees and the great sound of the wind going through those trees. . . no roar of the city. . . It's very very important that all of humanity, to get intimate, get back with nature in her earliest and most longtime relationships.

*So then you think that. . . the information seems to be more and more decentralized?*

That's the thing that's going on everywhere, yeah.

*And that will allow us to move out — the decentralized information will allow people to become more decentralized.*

I see the whole thing going on around our world today as a great educational process. Everything that's going on is super and great, . . . and all of it has to be. And everybody's learning lessons everywhere. They're learning that change is inexorable, and that change is not undesirable, even though it's unfamiliar, and even though you seem to be losing something that was familiar and that you thought was satisfactory.

*Do you know anything about the kind of housing and about the things that are going on in China and with the youth there and the kind of trends and directions. . .*

No. I wish I could be invited there, because I would like to work on it with them. But I know their own feeling and understandings of economy, of a long. . . they dealt with human excrement as valuable chemistry for a very long time in the Orient, and we haven't learned to do that here yet. . . so that I assume they're starting in a really very mature way regarding many of these things. It is possible that with the manufacturing of paper today. . . it's possible to make beautiful excrement collecting devices, packaging devices, to move the chemistry to where it does the most good. Very high energy content.

*What do you think is going to happen with what is going on with so many kids, where even though they're using very high-technology materials, it's very important for them to use their hands and to mold together their own dwelling, their own shelter, in the sense that. . . because of the economy that's possible with geodesics.*

The economy can look forward to allow them really to do their own exploring. You have a research laboratory going on with a kid right from the beginning. . . He's usually doing something quite mature — his intuitions are making him try those hands, but then he finds the things I've said a little earlier about what mathematics can really do for him — that one week of mathematics, he's suddenly a very different kid for the rest of his life. Very deep confidence. Then you can understand what a navigator. . . how great confidence comes to a navigator. When he can get under those stars. . . he's going to prize those beautiful tables that took so long for man to accumulate. . . You've seen the kids just hungry for the data of my geodesics. They're hungry for it. You've got kids that are catering to that because they see that hunger and they themselves follow it. But you've got to have my data.

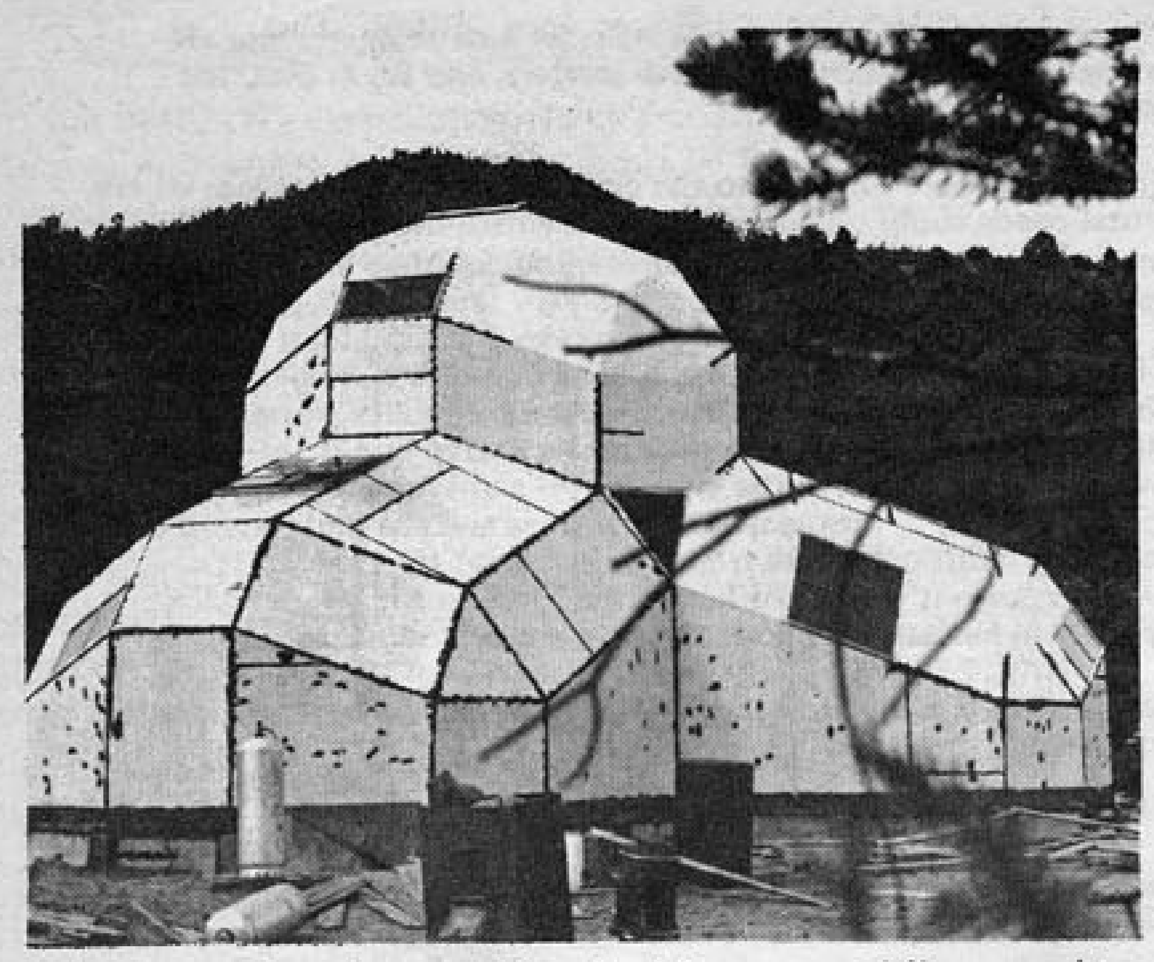
*One of our critical conflicts in feelings about the geodesics is the conflict between the economies that we see in high production and then the aesthetics that we can build into our own things to make them the way we feel good. And then to be out there doing it ourselves. . . and yet it's always so obvious that the thing could be mass-produced and come off the printing press, like the cardboard geodesics are, or out of Temcor or whatever. . . But there are the values both of making your own window patterns and using materials that are friendly. . .*

But after you've done it for awhile and so you really feel it and understand it, and you'll feel that, then, as I do today, that there are more important things to do. I got very excited while I was doing all the things that you're experiencing. . . you can imagine. As I got insights and invested time to really get the knowledge, and saw what man could really do, and I could really dream very far ahead, but, ah. . . there is a time when my. . . I might be more excited now by what this really means to humanity if I do other things than make those kinds. . .

*It's hard to see though how the aesthetic side and the importance of building your own shelter can be integrated with the economies of high production.*

There's a beauty — nature's own. . . her own appeal is built in here. . . so that kids will really begin to learn that. . . this way you learn to love the truth. You see, I want those kids to really make their own discoveries, and then once they have it. . . they're not going to necessarily have to do this — it's much more important — there are kids over here that are. . . have only just been born. They didn't come to put the geodesic dome together, and their mothers don't have time. . . and so we have to get the geodesic domes for them too. Okay? I just want kids not to be disdainful of the other man — in finding yourself you really ought to be finding the other man — that he has what you have — if you find something very exciting in you, he's got it in him too to be found. . . everybody has a right to do that. . .

# DROP CITY



*Peter Rabbit, who now lives in this zome at Libre, used to live at Drop City, and sent us these parts from his book:* Drop City,*Olympia Press, 1971.*

Drop City is a tribe-family/20 people living together in domes/man-woman-child/living/determined to live

It's impossible to define Drop City/it fell out of a window in Kansas five years ago with a mattress & a balloon full of water & landed in a goat pasture near Trinidad/at first Droppers made it tent & outhouse/tarpaper & bottletop/then others got a glimpse of the vision & started making it too/now there are twenty Droppers & as many visions & as many ideas of what Drop City really is

Drop City is a fucked up mess/Drop City is *completely open*/ completely free/I own it/you own it/because we know that all energy comes from the same place/10 domes under the skydome overshadowed by the Rockies/silverdomes/domes that are paintings/ multicolored cartopdomes/one black dome...

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Droppers live out of the garbagedump/we know about garbage/ the people of Trinidad call us Dump City/ they know where it's at/they call Droppers when they want garbage picked up/it delights them to watch us rummaging around in the schmutz/it delights us/an incredible number of people can live off the garbage heap of the U.S. Drop City is built on the garbage dump of a dying town of ten thousand strung out coalminers/think what can be done with L.A. - N.Y. - San Francisco - Des Moines - Dallas/The most beautiful place in Drop City is the dump/the garbage dump of the garbage pickers/ it's our greatest resource...

Domes use materials in the most reasonable efficient way. Bucky Fuller gave Drop City the 1966 Dymaxion Award/for poetically economic structural accomplishments/soon domed cities will spread across the world/anywhere land is cheap/on the deserts/in the swamps/ on mountains/tundras/icecaps/the tribes are moving/building completely free & open waystations/each a warm & beautiful conscious environment/we are winning

Droppers make movies/black & white snow-wind poems/flickering tv beauties with all the subliminal delights of pulsing coke ads/the crystal-molecular good sense of a dome going up time lapse/the grunting goodness of eating & sex/we want videotape recorders & cameras/strobes—hundreds of them/tape decks & amps & echo chambers & everything/we want millions of green energy flakes/we want to use everything new junk good bad to make limitless things/ we want an atomic reactor...

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Luke had all the panels ready to be put together when he arrived/he & Orville had cut the tops from junk cars with an axe/if you cut carefully around the edge you can get a 3½' X 7' sheet of 27 gauge steel with a baked on enamel surface from each car/3½' X 9' from station wagons/ Droppers loved station wagons and panel trucks sent us into paroxysms of ecstasy.

After the tops were chopped out Luke put a template of a given module on the top & outlined it with chalk/there was a 1" lip on each side of each panel/the module was then cut out with a heavy duty electric sheet metal shears/it takes 10-15 minutes to cut out each panel/ after the modules are cut the lips are bent over at 90° with a sheet metal break/holes are drilled in the bent over lips & the panels are fastened together with sheet metal screws/fast efficient cheap/we also used the insulation from the cars/the inside skin was made from old paintings by Clard & Lard & Wop

Luke brought three people with him to help put up the Cartop Dome/ it took the Droppers & Luke's crew 2½ days to put in the foundation & get the entire dome up/Clard & Lard put in a floor/some windows one was a broken plate glass masterpiece from Jennie's Lounge in Trinidad/it had half a funky Hawaiian hula chick painted on it/a pot belly stove/ & moved in

After we built the Cartop we realized that everyone in the world can have a beautiful comfortable dwelling unit for less than $1000/low cost housing units that are being built now cost at least ten times that much/what incredible waste & stupidity

●

Luke Cool caused a major change in my life/before I had always scrounged out of necessity/now it's a matter of choice/how in God's holy name did the American ideal ever get to be festoonmobiles-Hostess Twinkies-Coca Cola & crackerbox houses while our brothers in the rest of the world don't even have food & shelter/now here we are/the wreckage children/thank you Grover

In any feed store in the country you can get corn chop - soy meal - whole wheat - wheat shorts - dry molasses - pinto beans/good stuff for 5¢ a pound or less/to make your body super healthy/in any junkyard in the country you can get cartops from 15¢ to 40¢ each/ sometimes the junkmen even give them to you free just to watch the crazy hippies bust their asses choppin um out/build yourself the most outasight environment you can imagine/livin in the USA

●

The next project Luke Cool took on at Drop City was the building of the Complex/by this time there were four families plus Clard & Lard in D.C./a constant stream of visitors were coming to see where it was at in the great American southwest/at almost every meal there were 20 people eating in the 20' diameter kitchen dome/it was simply too small/we had a meeting & decided to write Luke & ask him to design us a multi-purpose space that would serve D.C. forever/he sent us a model of the Complex/a triple fused rhomba-icosa-dodecahedra/each of the three domes wld be 35' in diameter/it was perfect

Luke came & we mounted an electric saw on a table in the middle the land/we started making lumber runs to Pacific Studs in Cimarron, New Mexico/buying 8' cull 2 X 4s for $10 a unit/1200 board feet/ the man who ran the yard was a chicano named Tony/he was super to us & still is

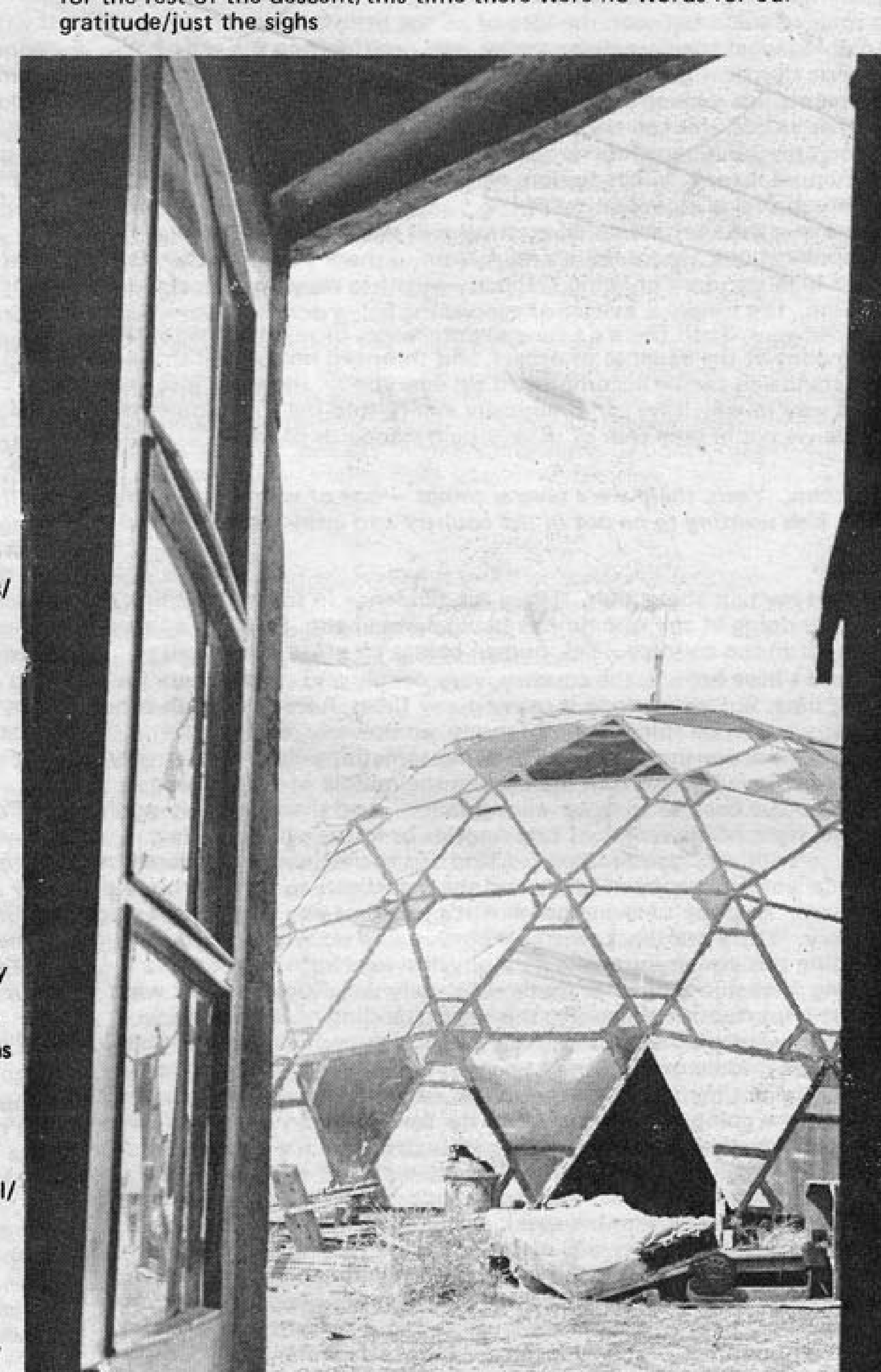
We nad some really memorable runs to Cimmarron/we'd always get stoned on the way down/way overload the red Dodge Dropper truck once we got there/then pray & curse the old wreck back over Raton Pass with the brakes smoking & the radiator steaming

One time Curley & I made the run pulling a trailer/we picked up 2 units/about 6000 lbs on a 3-4 ton truck/it was an insane load/we had to stop every 10 miles to fill the radiator/then going up the Pass/ almost to the top/the radiator cap blew off & drowned the motor/we were roaring backward down the steepest part of the grade/the trailer pulling the truck/we yanked the emergency brake/it started smoking immediately/we jammed on the brakes/the pedal went straight to the floor smoking & squealing in protest/there was a big semi coming up the grade being passed by a car/both lanes full/it looked like we'd bought it/off the road was a cliff/200-300 ft. straight down/O Shit Curley/there was only one thing left to try/we engaged the crash rail with the side of the truck & trailer & finally came to a screeching grinding stop/whew

We sat in the cab for about 15 minutes saying nothing/Curley lit a joint & passed it to me/we smoked in silence/finally Curley sd/Thank You Cosmic Forces/I sighed a devout amen

I tried the engine/the temperature guage had gone over the top/the needle disappeared never to appear again/but the engine caught/I socked it in granny low and scraped away from the crash guard/up/ up/& over the summit

We were laughing & bouncing up & down on the seat & were so happy I forgot to downshift into third for the descent/by the time I remembered it was too late/Jesus/here we go again/55/65/75/ absolutely no control/absolutely no brakes/the trailer was sluicing back & forth crazily/trying to pass the truck/everything felt all spongy/ hearts in throats/85/& here comes the big curve/Curley scrunched down in the seat so he cldnt see/sweat was popping out all over me/O sweet Jesus/& then we were around the curve/we broke on thru to the other side/I must've blacked out/to this day I have no memory of making that curve/maybe a kindly Cosmic Hand lifted us & put us back down on the straightaway/then there was a little upgrade slowing the truck just enough so I cld get the truck into third for the rest of the descent/this time there were no words for our gratitude/just the sighs



The modules in the Complex were pentagons - squares & equalateral triangles 8' on a side & well braced/ one crew worked at the saw/ another went on lumber run/the third hit the junkyards from Santa Fe to Pueblo chopping tops/Luke Cool generally went out with the cartop crew since he cld chop an average of 8 tops an hour/the most I cld manage was 5 an hour

The first time out/the Wop & the Rabbit at Manascalco's junkyard in Trinidad/nothin to it/a cinch/take the old axes & chop um out/I really dig junkyards/junkyard angels/that's us/ yeah

There was a Mexican at the junkyard/Hay jouse/heepies/I cant make no mownee at 30¢ a top/jouse got cheekens out dere/I trade jouse for some cheekens/jouse got a goat out dere/how old dat cabron/he been cut yet/them cheekens lay las weenter

Wait a minute/wait a minute/we sd/we'll give you 25¢ a top/no mas/ two bits/no mas/ok

Ok heepee/weel see

We chopped out about 20 in the junkyard swelter & reflection/workin our asses off/dangerous/razor sharp axes skittering off the steel/slicing at legs/when you hit one of the roof supports an incredible jolt travels up the axehandle & paralyzes your wrists & hands/jagged steel edges catching clothing/tearing flesh/hands stiff/clenching/clenching/after chopping for an hour if you try to open your hands the fingers insist on closing themselves into fists again/blisters/blisters on top of blisters/bone weary

The Mexican watched us work/he was impressed out of his mind/jouse heepees choor work/huh/hombre/mucho trabajo/jouse guys choor work/jouse come back manana/huh/hombre/we find jouse mas tomorrow/huh/hows about them cheekens

The Wop & I fell out/but were back in the morning cutting/cutting/ more weary than weary/but cutting/Luke Cool returns/cut more/ Pueblo/Walsenburg/Raton/in Raton Lard & I went to a junkyard run by a heavy middle aged woman named Dutch/toughern shit/but she was butter in Lard's hands/she got all mushy eyed when she saw him/we got her tops for 15¢ apiece

About halfway thru the day at Dutch's Lard was working on an old Hudson/they dont have roof supports/he was on top & had two sides completely cut out & the third side about 3-4ths cut/he lost his balance & put his full weight on the top/the top went down inside the car & Lard went sprawling with it/the top sprung back up & Lard was caught between the two jagged edges like a giant sissors/it cut him up pretty bad/but Dutch was super & did a fine doctoring job on his cuts/she got all soft & femine & spent the rest of the day serving us lemonade & donutes & stuff

By this time we had enough tops to start fabricating the panels/we put together the triangles - squares & pentagons/braced them up good then started nailing the cartops to the shapes with roofing nails

Green red black white blue gray/every concievable color cartop/a rainbow dome/a parking lot

And the thumbsmashes/two guys worked on each shape/you cant drive roofing nails thru cartops so one guy punched holes & the other drove nails/both the punching & the nailing made the metal vibrate/ punch & nail skittering/22 oz hammers/smash/fuck/goddam motherfucker/shit/chinga/Ifucking quit/Iaint handlin this pieceashit garbage again/I aint handlin none a this shit/thumbs swollen/ swollen/fingernails black/it hurt so bad/so bad/but the next day we were at it again/we measured progress on the Complex in thumbsmashes

The building of every dome I've ever worked on has evolved its own language/beautiful & really real

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Luke Cool & the Wop made the last cartop run/they had to go to Santa Fe to get the final bunch/200 miles/we'd gotten everything closer/after getting all the tops they cld find they were still one short

Whatre we gonna do Wop/sd Luke as they were driving along/we cant go back only one short/we just cant

They were passing thru Taos/it was after midnight/motel after motel lined the highway/the last motel on the edge of town was almost dark/ the only light came from a small neon NO VACANCY sign/Luke pulled off the road

Shall we/sd the Wop reaching for his axe

After you Alteresio/sd Luke reaching for his

The car nearest the road was a shiny brand new gold Cadillac/it was fated/they climbed onto the car/one on the hood the other on the trunk

In cutting cartops the first lick is the hardest/if you dont get it just right the axe bounces off the solid surface/but once it's started you just work in the previous cut/sort of like a canopener/the first lick is also the one that makes the most noise

They raised their axes together/Luke nodded his head & both tools came down as one/THUNK/two perfect cuts/they waited a few minutes to see if the noise had awakened anyone/all was quiet/they went back to work making sure every chop was efficient & was as silent as possible/inside of ten minutes the gold Cadillac was topless & the Wop & Luke were back on the road grinning to themselves in the dark cab of the pickup

A good night's work/sd Wop

I'm only sorry about one thing/sd Luke laughing/I'm only sorry that I cant be there in the morning to see that mother's face when he discovers that his shit mobile turned convertible overnight

●

Droppers have learned how to build beautiful houses out of cartops for less than 200 dollars/less than $100/we know how to use solar heating/we're hip to windpower/Droppers know how to best use the government doles & poverty programs/each dollar we use is one less that goes into the making of napalm/every cent that Drop City uses is one less that goes to those insane retarded creeps in Washington...

The story of Drop City will never end/it's the story of man on the road to free...

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# BAMBOO DOME

Bamboo grows fast, is free material for a dome framework. It might be possible to suspend a tent skin or mosquito netting inside, or pull a stretch cloth over the outside and shoot foam. Tools: a pocket knife and string. The following instructions were prepared by R. Buckminster Fuller. We haven't tried such a dome yet.

## DOME ASSEMBLY

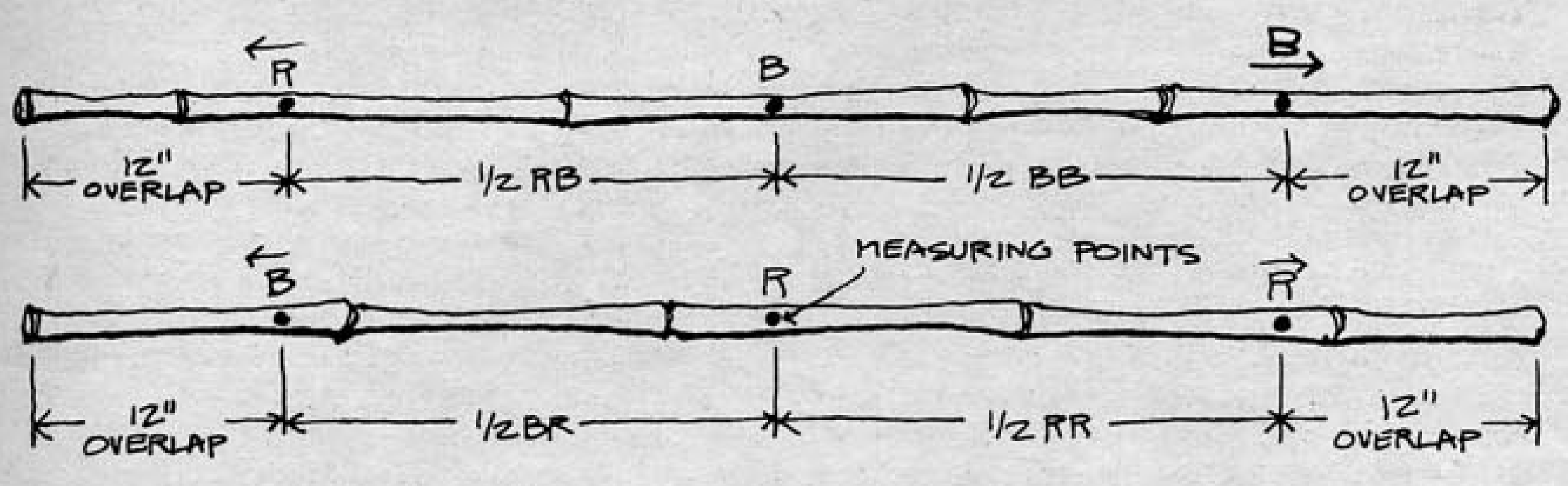
*The geodesic dome, as shown in the assembly diagrams, contains two different joints: a "B" joint which occurs at the vertices of all the pentagons formed, and an "R" joint which occurs at all other points.*

*The spans from joint to joint are BB, BR, or RR. The arc factors of these lengths are: BB = .26030616, BR = .31030984, RR = .32636688.*

*For these factors, the radius of the dome is 1.00. To construct a 22' dome (11' radius) the lengths of the arcs would be as follows: BB = 2.86', BR = 3.41', RR = 3.59'.*

## CUTTING, MEASURING THE MEMBERS

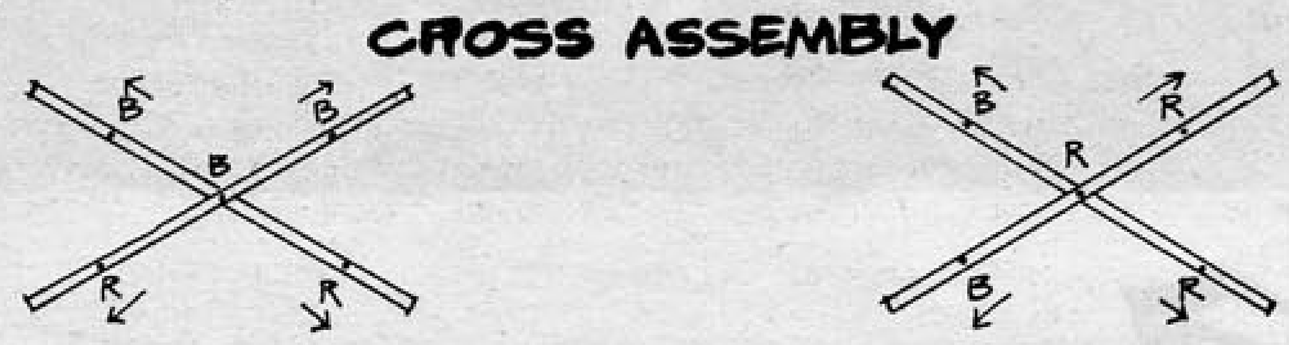
*There are only two different lengths of members used in the erection*




*For a 5/8 dome, 80 "B" members and 90 "R" members are required.*

*A line of color can be drawn around the bamboo members at each measuring point. Use blue for the "B" points and red for the "R" points.*

## CROSS ASSEMBLY

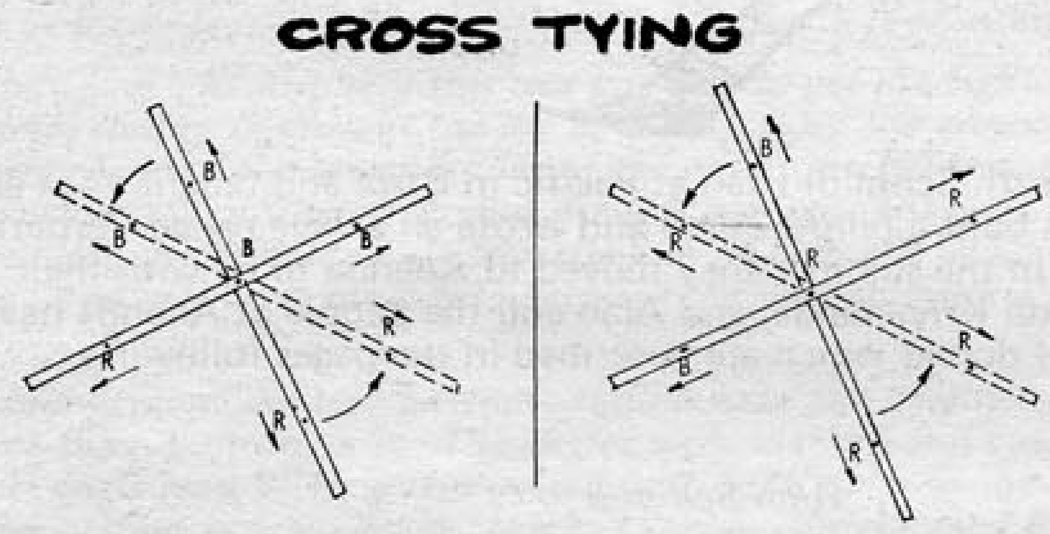


*The "B" cross consists of two "B" members whose lengths are: ½BB plus ½BR plus 12" extra at each end.*

*The "R" cross consists of two "R" members whose lengths are: ½BR plus ½RR plus 12" extra at each end.*

*With 12" extra on the end of each stick, there'll be a 24" overlap when the crosses are assembled.*

## CROSS TYING

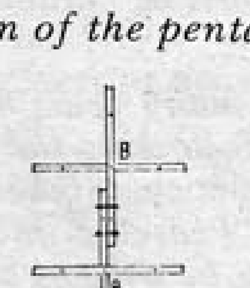


*Place members at right angles to each other and tie firmly, but not too tight. During assembly of the dome, the crosses will twist into proper position as shown.*

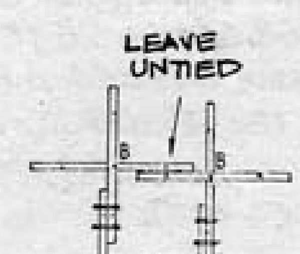
*In all cases, when looking at a cross with the acute angles at the sides and the obtuse angles at the top and bottom, the member going from upper right hand corner to the lower left hand corner always passes over the other member.*

## STAGE 1 ASSEMBLY

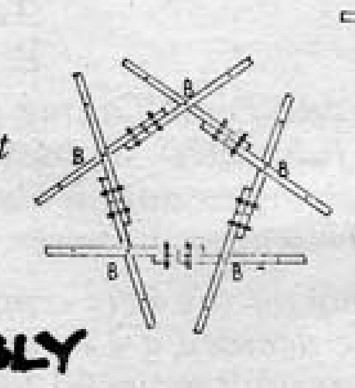
*The first stage in the assembly of the dome is the construction of the pentagon at the top of the dome. This process employs five "B" crosses.*



*Step A: Tie together two "B" crosses as shown in the diagram. Note that the end measuring points have the same designation as the cross to which they are connected.*



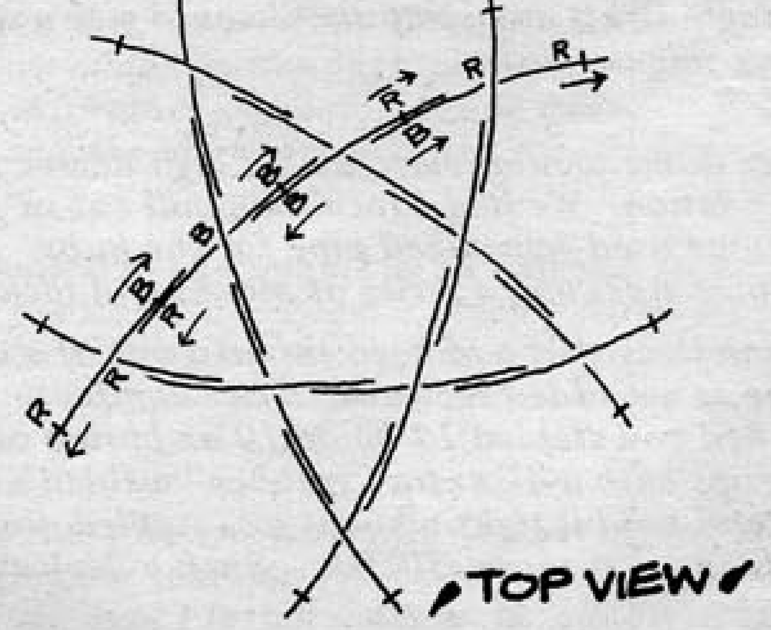

*Step B: Add two more "B" crosses in the same manner as shown in step A.*



*Step C: Add fifth "B" cross between the untied legs. In order to insert this cross, all crosses will be twisted so that a regular pentagon is formed.*

## STAGE 2 ASSEMBLY

*The second stage consists of closing the five triangles around the pentagon. Use five "R" crosses.*



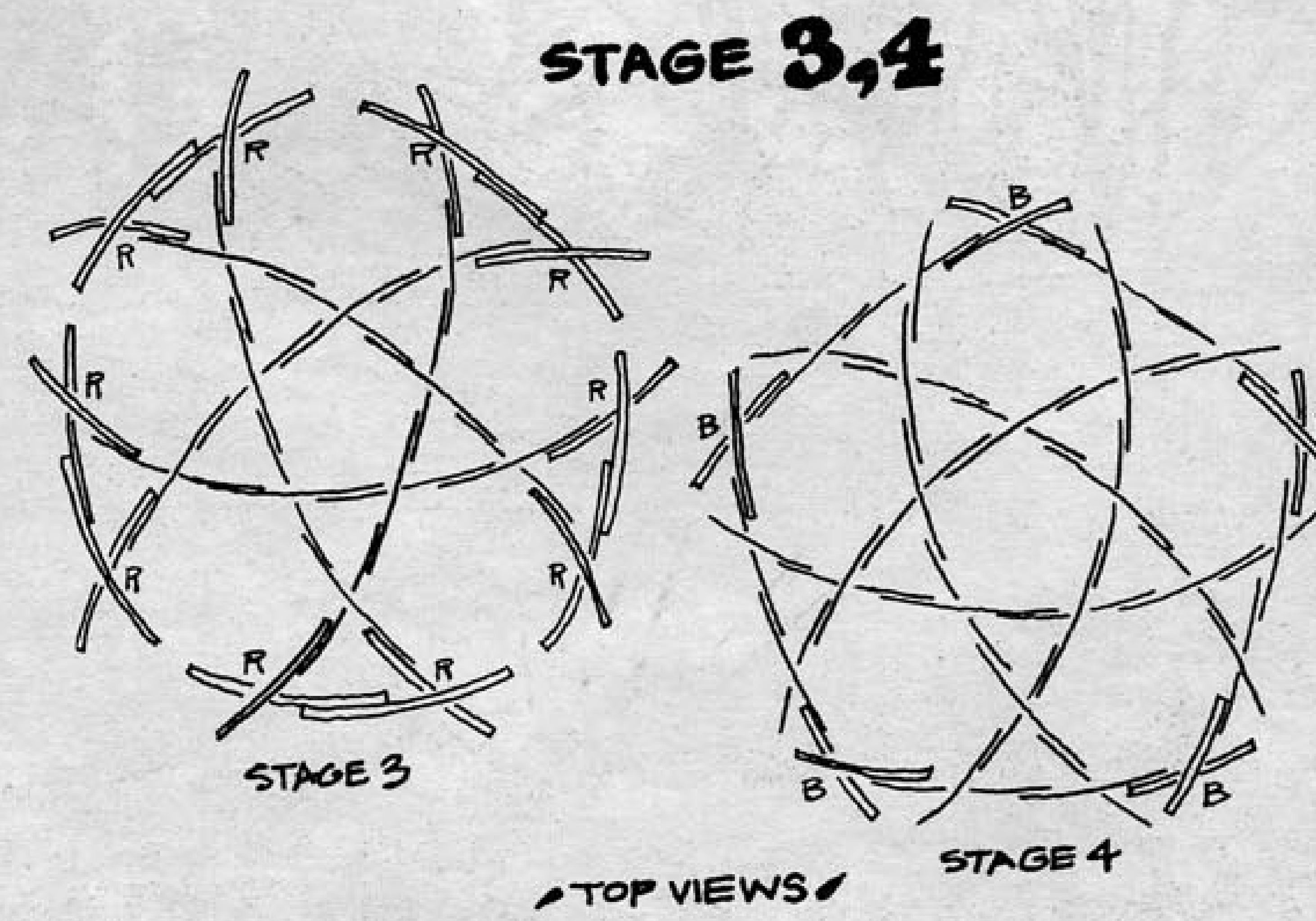

*Again, the end measuring points always have the same designation as the cross to which they are connected.*

*At this point, the structure will tend to bow. Turn the figure so that it is concave downward.*

## PROP IT

*Lift the assembled figure off the ground to facilitate the addition of new crosses. Use five bi-ped props. Each prop consists of two bamboo sticks about seven feet long, tied together near the top with a cord about a foot long. These props will then support the dome at equidistant points from its apex; first at the five vertices of the top pentagon, later, at five correcponding points on the top five hexagons.*


## STAGE 3,4

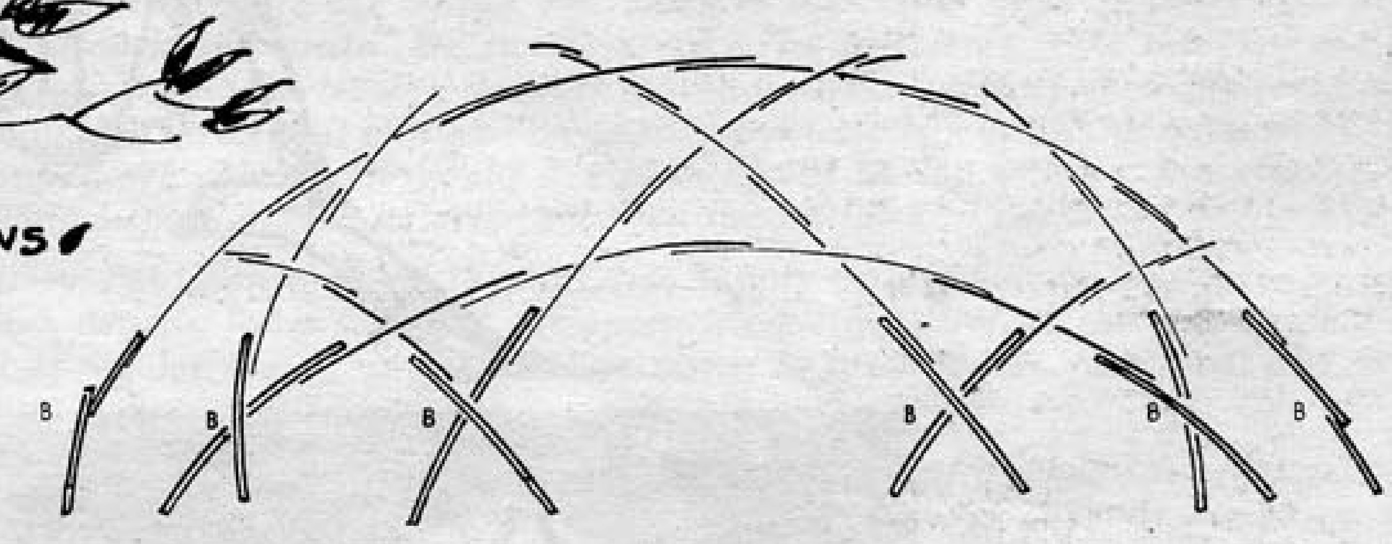



*For third stage use ten "R" crosses as shown. The rest of the diagrams, the "B" crosses will be shown by a heavy line, the "R" crosses by a light line, and all newly added crosses by a double line.*

*The fourth stage uses five "B" crosses which close the five hexagons.*

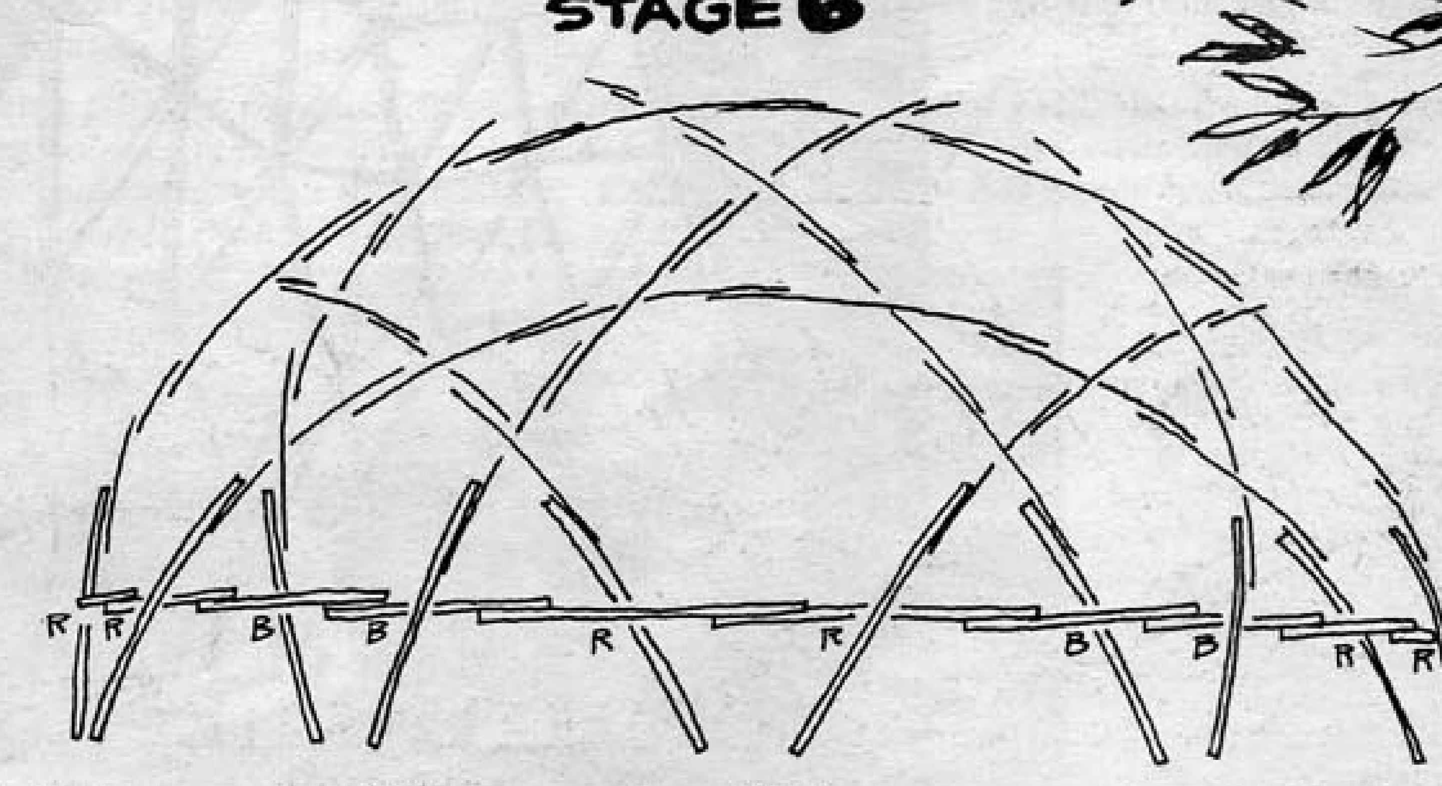
## STAGE 5

SIDE VIEWS



*The fifth stage uses ten "B" crosses to close ten triangles. Six of these crosses can be seen in the elevation above.*

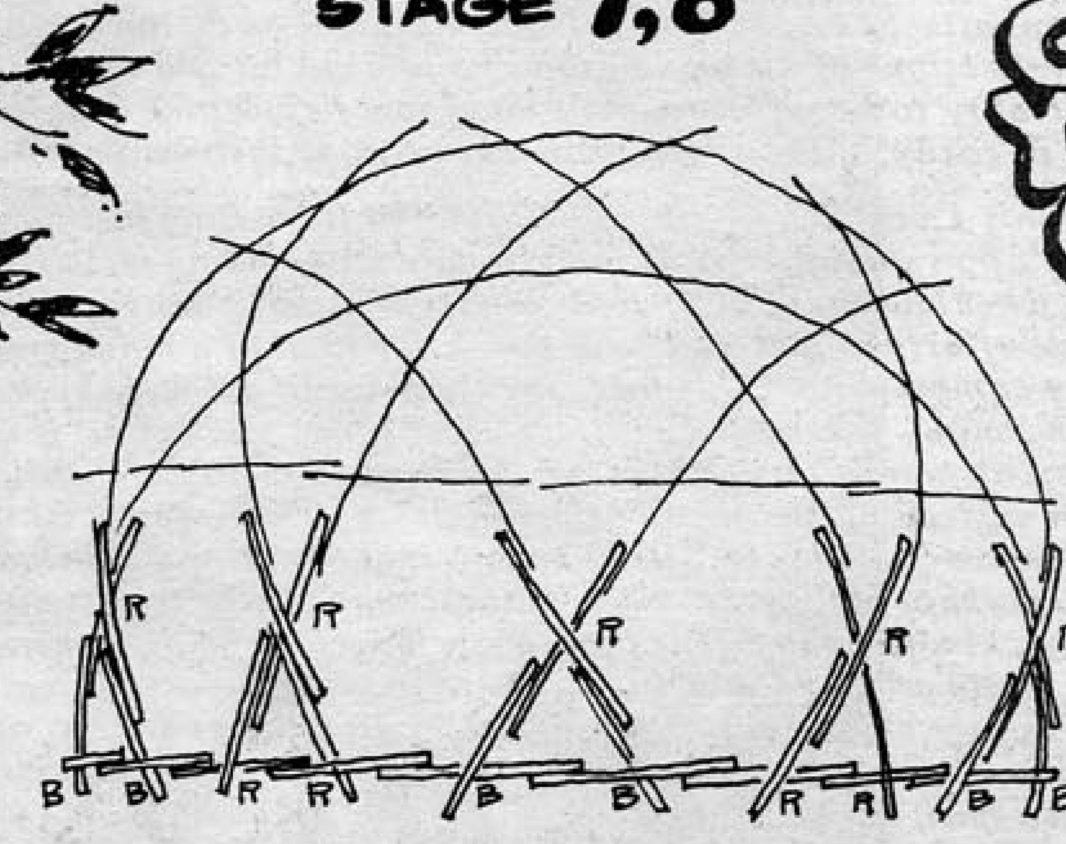
## STAGE 6



*The sixth stage uses ten "B" crosses and ten "R" crosses to complete the first horizontal band. We now have a 3/8 dome.*

## STAGE 7,8

GROW YOUR OWN



*To complete the 5/8 dome requires two stages. The seventh stage uses ten "R" crosses and the eighth stage uses ten "R" crosses and ten "B" crosses.*

*On the last twenty crosses, all members pointing towards the ground should be cut off 12" from the cross' central point.*

# Ananda

*The dome is interesting not only aesthetically or mathematically, but also philosophically and spiritually. Everything that man does is, in a sense, a statement of his outlook on life. A stiff mind will generally be attracted to straight, not to curved, lines. A materialistic person, attached as he is to solid matter, will be inclined to construct firm, heavy buildings—reflections of his own vision of a world that will endure forever. Insular people, fancying reality to be no larger than their own definitions of it, like their homes, too, to box them in cozily, shutting out from their minds the vast universe outside.*

*We have come, in this Twentieth Century, to a time of increasing mental fluidity, and of decreasing reliance upon solid matter as the ultimate and abiding reality. We have come to an age, finally, when our mental concepts are seen, not as realities in themselves, but only as our humble efforts to reach out and touch the hem of a much greater reality that we can only dimly comprehend. The dome is expressive of our new approach to the universe. It is in harmony with the scientific concept that space itself is curved. In its roundness it represents our modern desire for continuous mental expansion, for reaching out to the universe instead of boxing ourselves in protectively against its immensity. The dome seems in some way to be more conducive to the mental and spiritual harmony of the dome dweller, perhaps because its more natural shape helps to attune him with nature instead of alienating him from it. Boxed houses belonged to an age when men stood in opposition to the world around them, in competition, as it were, with nature and the universe. Domed houses belong better to this age of growing awareness of man's need to* cooperate *with nature if he is to progress further, or even to survive the destructive forces that his competitive spirit has unleashed.*

*Swami Kriyananda*

Last year Alan and Heath Schmidt lived at Pacific in a tipi and taught yoga and gardening. They then built a pillow dome and wrote an article called Centering for Domebook One. In the summer they moved to Ananda to be with their spiritual advisor, Swami Kriyananda, and Alan and the people at Ananda have since built a variety of domes which are described in the pages following.

*Alan Schmidt*

*Ananda means bliss and it is the name of our meditation retreat and co-operative community. The Ananda Meditation Retreat is located on 70 acres on which there are a few domes and about 20 full time residents and sometimes up to 50 or more retreatants who come to study and meditate. Six miles away 20 families live on 280 acres that constitute the Ananda Spiritual Community or* The Farm. *Both locations are nestled in rolling forests of pine, cedar, oak, and manzanita at a 3000 ft elevation in the foothills of the Sierras near Nevada City and Grass Valley. The founding and directing of Ananda is guided by the spirit of Paramahansa Yogananda and by Swami Kriyananda, a direct disciple.*

*Kriyandaji has for many years been interested in geodesic domes and built the first domes at Ananda following the early Sun Dome plans that appeared in the May, 1966 issue of* Popular Science. *Since this time Kriyananda supervised the construction in 1968 of two 26 ft "Pease" domes and two 39 ft "Pease" domes. Last spring a 24 ft dome was added to be used as a kitchen. Last summer a "Pease" dome that was used as the temple burned to the ground and has since been replaced by a much larger and more beautiful structure. Also smaller Icosahedra and individual resident domes have been built.*

## Temple Dome

### Introduction

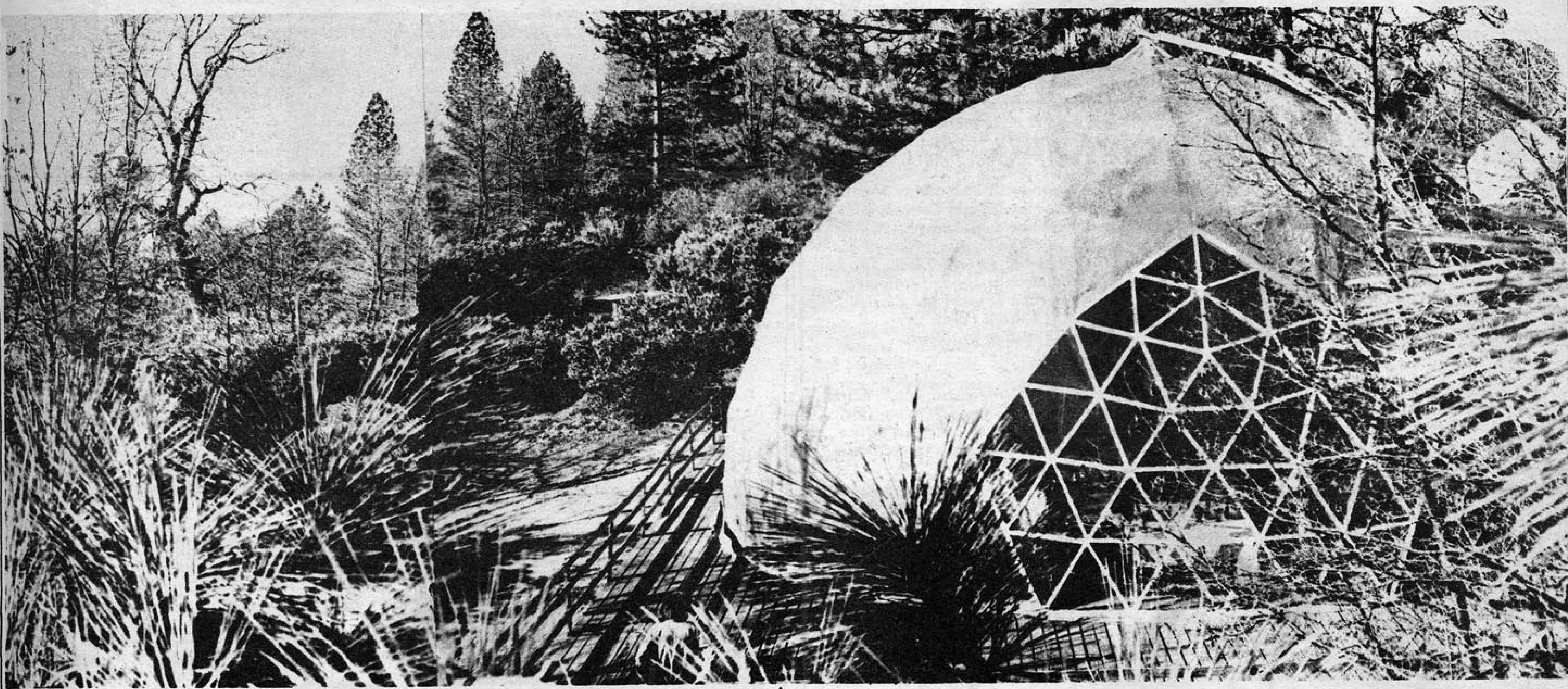
*The 38 ft plywood "Pease" dome that was being used as a temple burned down in less than an hour in July, 1970. It burned so quickly there was little chance to save it. The only thing interesting to note is that domes cave in not out and thus contain themselves. Please take fire into account when designing domes.*

*We began working on the new temple dome shortly after the fire. After constructing some models, we decided a 4-frequency hemisphere looked the best. Foam seemed to be the most interesting material to use to build it. We went to see John Nolan and tried out various methods and decided that foam shot on the inside against burlap gave the results we wanted. Even though the triangles, like in the previous "Pease" dome, were still big , by using foam, single struts and strap they would give a simpler appearance and the feeling of a free flowing singular unit.*

### Construction

*We figured a 44 ft diameter dome would relate with a high degree of structural integrity to what we left of the foundation. We had a local saw mill cut us Douglas fir to a true size 2" X 3" and bought some used galvanized pipe for the hubs. A 1" heavy cable was strung between two large pine trees and a series of blocks and tackles were attached.*

*We used 20 to 40 ft tall pine trees that had been thinned out of a nearby forest to brace different parts of the dome as we added sections. After completing the frame which took a couple of days we stretched and stapled 12' wide 10 oz burlap over the frame following great arcs. A pair of vise-grips with a 4" extra "grabber" welded on was used to stretch the burlap over the frame and hold it tight while it was stapled down. This saved a lot of wear and tear on the hands and was more efficient. Such a device can be purchased in large hardware stores.*



### Ladder

*To get up and over the dome to put on the burlap and spray the outside, we spent a lot of time on developing a ladder. Our outcome, however, was a barely passable arrangement. We describe it because a smaller design for smaller domes is quite satisfactory and you may be able to figure out some improvements for larger domes. We bought three 16 ft aluminum extension ladders and removed the excess hardware. We found out they can be ordered as sections without shoes, or extension supports, and either all upper or lower ladders. We laid these out in five 8 ft sections around the base.*

*Since we were building a hemisphere this was possible to get the right size. When building a 3/8 or 5/8 dome, simply figure out the arc and mark it on the ground. The bottom two sections were made of the lower ladder of the extension ladders, the middle was doubled like a regular extension ladder and the top two sections were made of the upper ladders. By doubling the middle the ladder size can be changed which we haven't found to be necessary. And mainly it takes into account the way aluminum extension ladders are designed.*

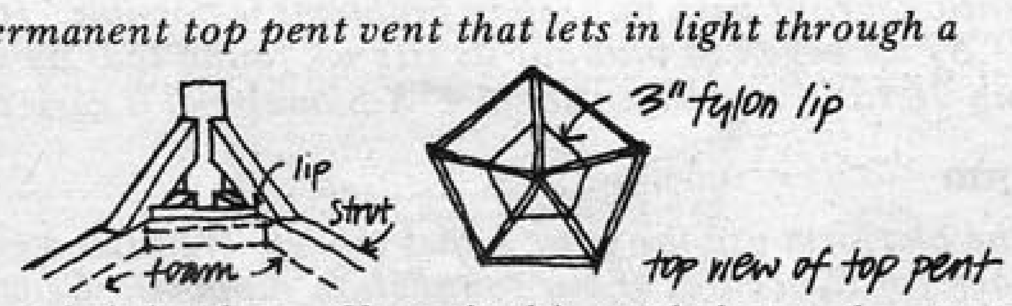
*In our special arrangement the two bottom sections have the channels pointing in while the two top have them pointing out. The angles were marked and cut. 1/8" thick, 1½" X 1½" steel angle iron 9" long was bolted with 3/8" bolts to the ladder to tie the sections together. Other braces of 1/8" thick, 1" wide straight steel 6" long was curved and bolted to the upper and lower channels. After the ladder was in place, cross ropes were tied to the middle of this huge affair and secured to opposite sides of the platform.*

*The ladder was secured to the top and made to pivot by extending the top hub and adding a series of pipes and welds.*

*Luckily for us Dick, the foam shooter from John Nolan's crew who worked on the outside, was the perfect lightweight acrobat and was as fearless as a tiger.*

### Top Vent

*We have a simple and attractive permanent top pent vent that lets in light through a smaller framed-in pentagon.*




*Foam is applied up to the lip and seals it in place. Clear vinyl is stapled over the struts and a 1" opening is left between the vinyl and foam for air flow. Battens are used to secure the vinyl in place.*

### Windows

*The windows are broken down by further triangulation. This gives a handsome effect and allows us to use 40" wide flexible material for our windows. Until we can afford more permanent material like acrylic plastic or butyrate sheets, our windows are made from 10 mil butyrate called Koda-pak. It is no longer being produced because I believe that like thin mylar it will split after a period of time where it is stapled or nailed to the struts. I see it in use as storm windows throughout the Sierras because unlike vinyl or polyethelene it is window glass clear. Battens with caulk underneath were nailed over the windows to the struts. Care must always be taken at the hubs, so we put the longer battens over the dome struts and then fit smaller battens over the added 2 X 3's.*

*After the dome was foamed the inside of the temple was sprayed with intumescent fire retardant paint to which we added just enough pigment to give a pale blue coloring. With the paint to reflect light, this rather small number of windows is just perfect. It brings our attention to the east and the altar and gives the whole dome a feeling of a vast cave.*

### Entranceway

*An Icosahedron was appended to the temple as an entranceway. A stairway leads from the ground up into the Icosa under a triangular awning formed by the top of the Icosa. The doorway and triangular awning are formed by leaving a base down triangle open and shaping burlap from it to a door frame inside.*

### Emergency Exit

*An emergency exit was created by stretching burlap between 2 X 3 supports and a door frame. This gives a free flowing rounded effect. Since we don't want this exit to be used except for an emergency we didn't install a door. We simply stapled clear vinyl on the outside of the door frame. This gives us a little more light and if needed for an emergency the vinyl can be easily pushed out.*

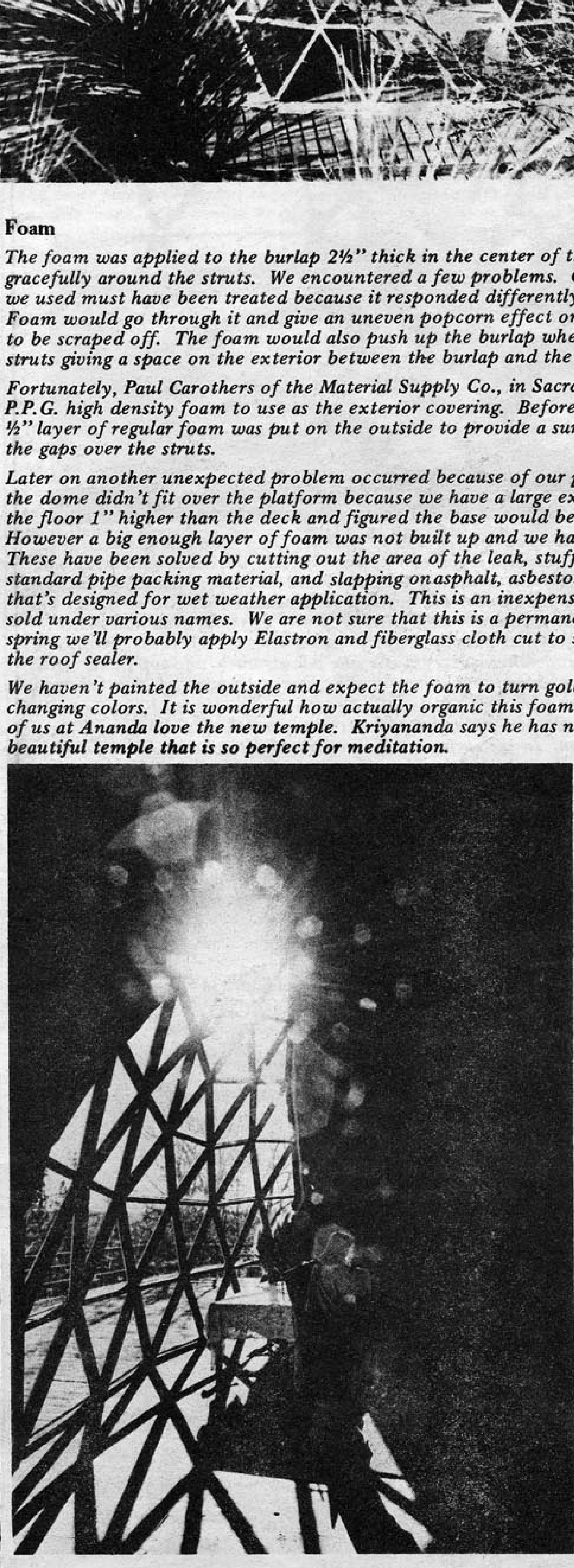
### Foam

*The foam was applied to the burlap 2½" thick in the center of the triangle and flowing gracefully around the struts. We encountered a few problems. One was that the burlap we used must have been treated because it responded differently than the test panels. Foam would go through it and give an uneven popcorn effect on the outside. This had to be scraped off. The foam would also push up the burlap where it was stapled to the struts giving a space on the exterior between the burlap and the wood.*

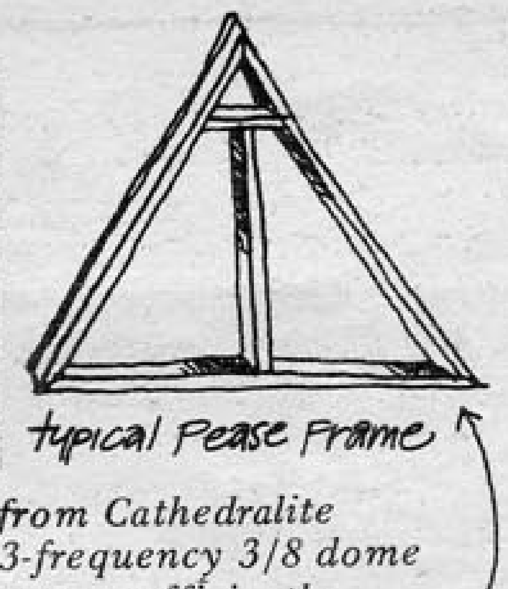
*Fortunately, Paul Carothers of the Material Supply Co., in Sacramento, gave us some P.P.G. high density foam to use as the exterior covering. Before this was applied a ½" layer of regular foam was put on the outside to provide a surface for it and to cover the gaps over the struts.*

*Later on another unexpected problem occurred because of our platform design. Since the dome didn't fit over the platform because we have a large extended deck we built the floor 1" higher than the deck and figured the base would be sealed by the foam. However a big enough layer of foam was not built up and we had numberous leaks. These have been solved by cutting out the area of the leak, stuffing in Oakum, an old standard pipe packing material, and slapping on asphalt, asbestos, plastic roof sealer that's designed for wet weather application. This is an inexpensive product that is sold under various names. We are not sure that this is a permanent solution, so in the spring we'll probably apply Elastron and fiberglass cloth cut to size over the areas with the roof sealer.*

*We haven't painted the outside and expect the foam to turn gold. We notice it gradually changing colors. It is wonderful how actually organic this foam structure can feel. All of us at Ananda love the new temple. Kriyananda says he has never been in a more* ***beautiful temple that is so perfect for meditation.***



## Pease Domes

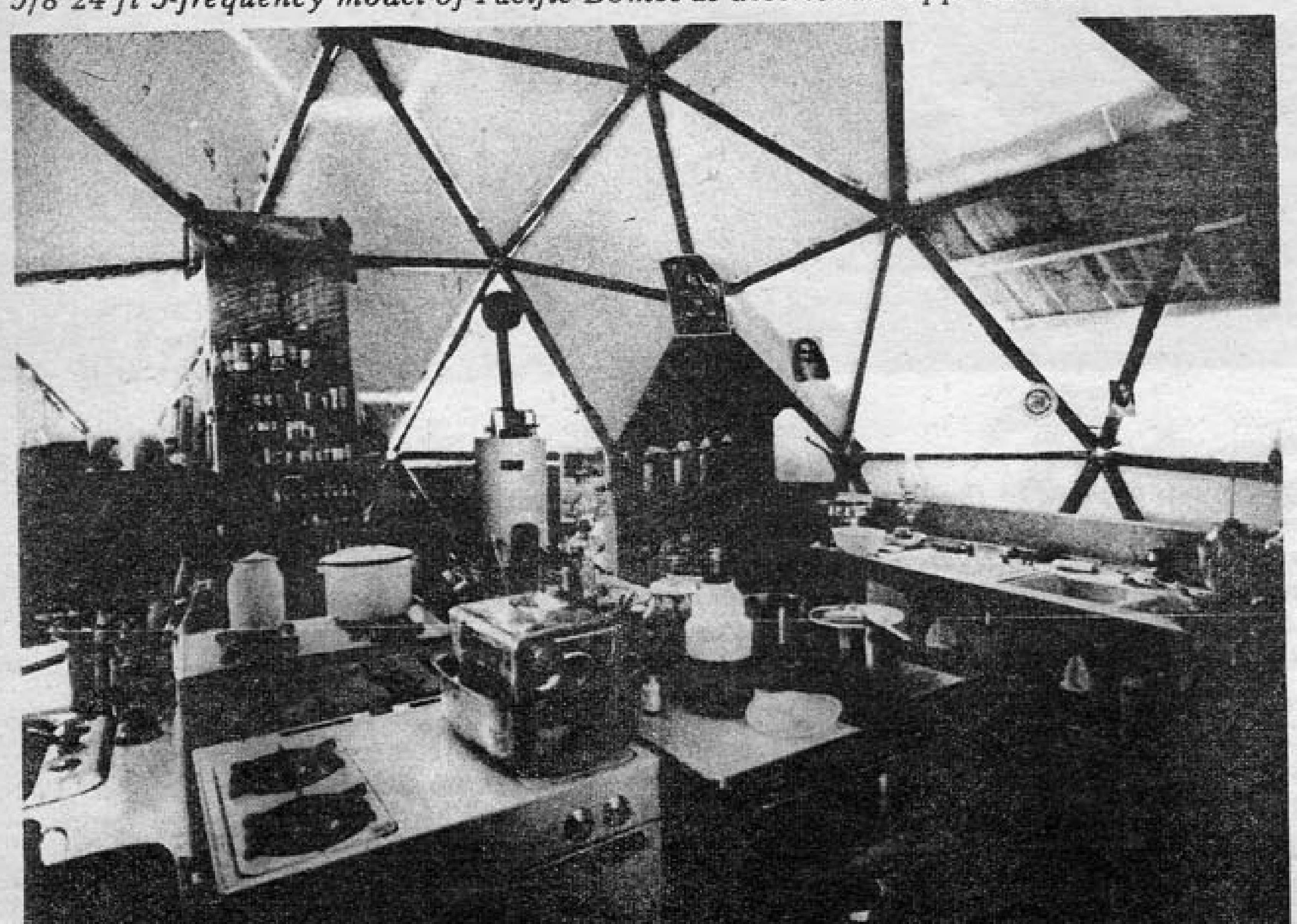



The "Pease" dome is a plywood sun dome available in kit form from Cathedralite Domes in South San Francisco. Two sizes are available, a 38 ft 3-frequency 3/8 dome and a 20 ft 2-frequency hemisphere. These sizes use 4 X 8 sheets very efficiently, however the triangles appear bulky and heavy because a brace is needed that runs through an altitude of the triangle.

Like many plywood domes leaking has been a problem. The Candlelight Company suggests using GE Silicone Caulk after any old caulk and tape is cleaned away and a ¼" channel is cut with a rotor. We have been highly satisfied with the results obtained by using Elastron No. 850 (United Paint Manufacturing Inc., 1130 E. Sprague Ave., Spokane, Washington) and 3" wide fiberglass tape. First a coat of Elastron is applied followed by the tape and another coat of Elastron over the tape. The tape absorbs the Elastron. The method was suggested by John Nolan and an engineer at United Paint. We recommend this technique as a method to use in dealing with sealing problems.

## Kitchen Dome

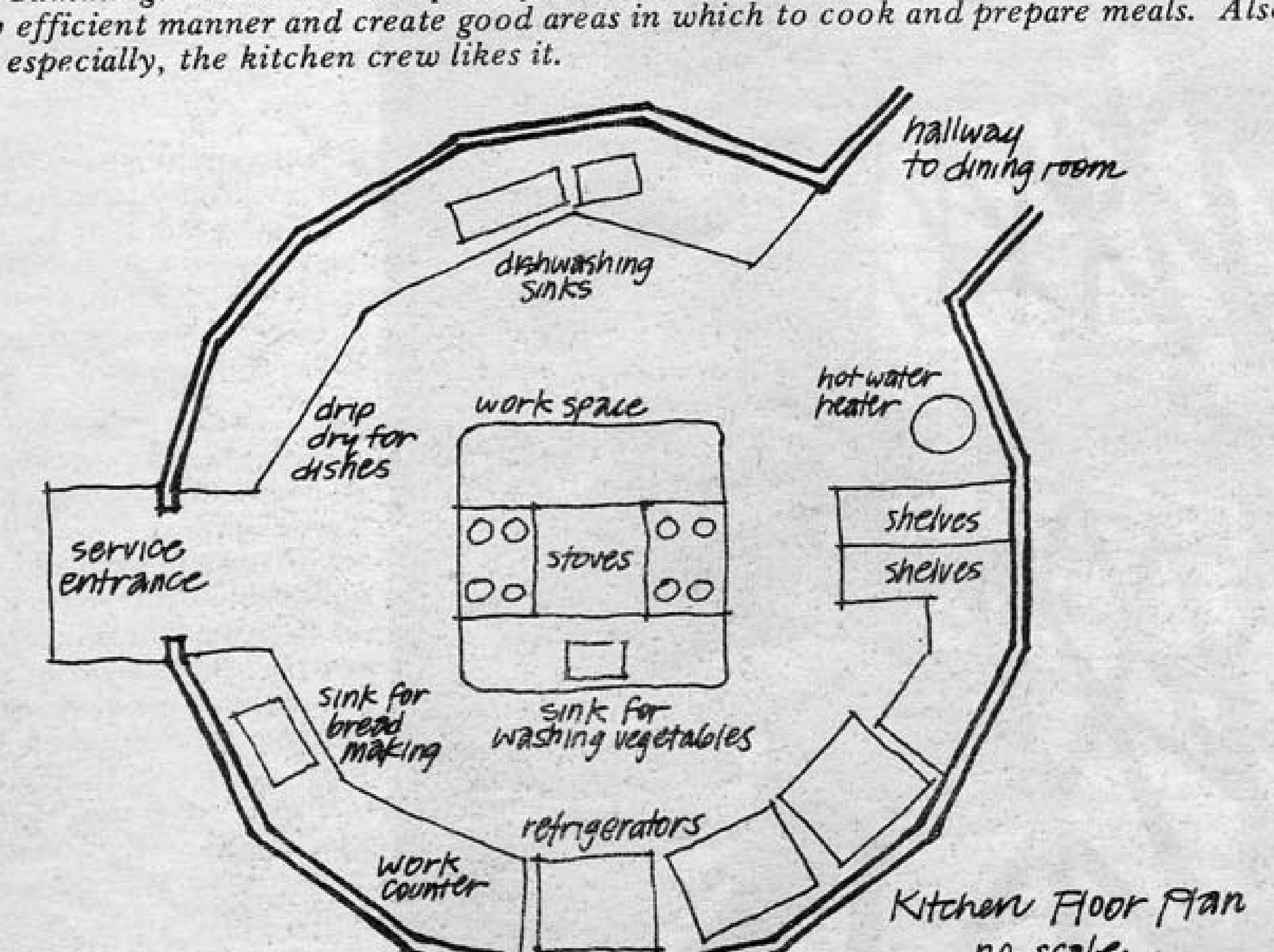
In the winter of 1967 we arranged for Kriyananda to visit the testing grounds of Pacific Domes. He was highly impressed. He liked the fact that Pacific domes felt expansive, appeared very light in weight and were very close to spherical. Shortly after his visit a new dome to be used as the Ananda Retreat's kitchen was planned following the basic 5/8 24 ft 3-frequency model of Pacific Domes as described on pp. 20-23.



We used 10 oz Fylon (fiberglass) cut out of 4 X 12 sheets. The Fylon is translucent, lightweight, easy to maintain and the seams can be overlapped. We cut it with a skil saw and masonry blade. It is important to wear a face mask and air filter mask when cutting fiberglass. Tube caulk was applied under the overlap, strip caulk could also be used. The Fylon was secured in place by aluminum nails with neoprene washers. Nail holes had first to be made with a heavy center punch. White pressure sensitive vinyl electrical tape was applied to the vertical seams that run from the side pentagons to the top pent. This proved unsuccessful and for a stopgap measure once the leaks begain in the fall, Elastron No. 850 was applied over the tape. We have applied a number of coats of Elastron and are highly impressed that it worked just by slapping it over the failing vinyl tape. This is not however a real solution. In the spring we will replace this tape with Elastron and fiberglass tape as previously described and add a color coat of white Hypalon, also a product of United Paint.

During the summer the Fylon on the south side lets in too much heat so reflective metallation, i.e., aluminum foil with Kraft paper backing, was placed up inside the triangles with the reflective side facing the outside. Both Reynolds and Kaiser make this product. We like the Reynolds best because the Kaiser foil has its name written all over it and this shows through the Fylon on the outside. Pop in styrofoam panels were used for insulation. Condensation easily occurs on the Fylon so adequate ventilation is necessary. We have a permanent vent at the top and one opening panel at the top and three at the base besides the two doors.

Jim Cummings worked out the plans for the interior. His plans use the floor space in a very efficient manner and create good areas in which to cook and prepare meals. Also, and especially, the kitchen crew likes it.

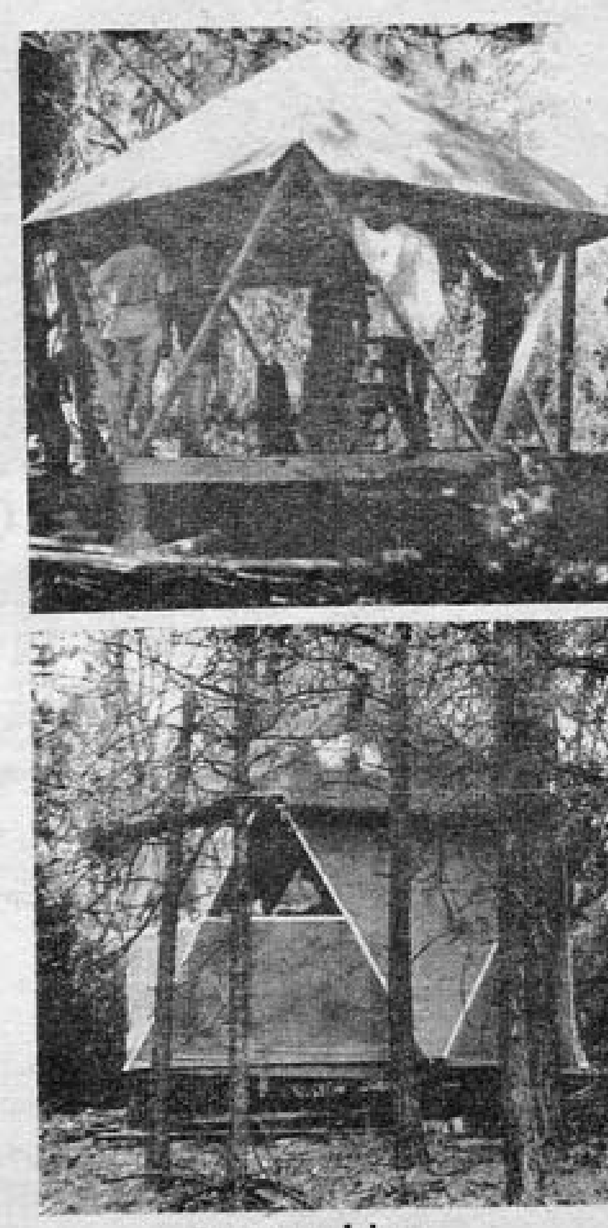



## Resident Domes

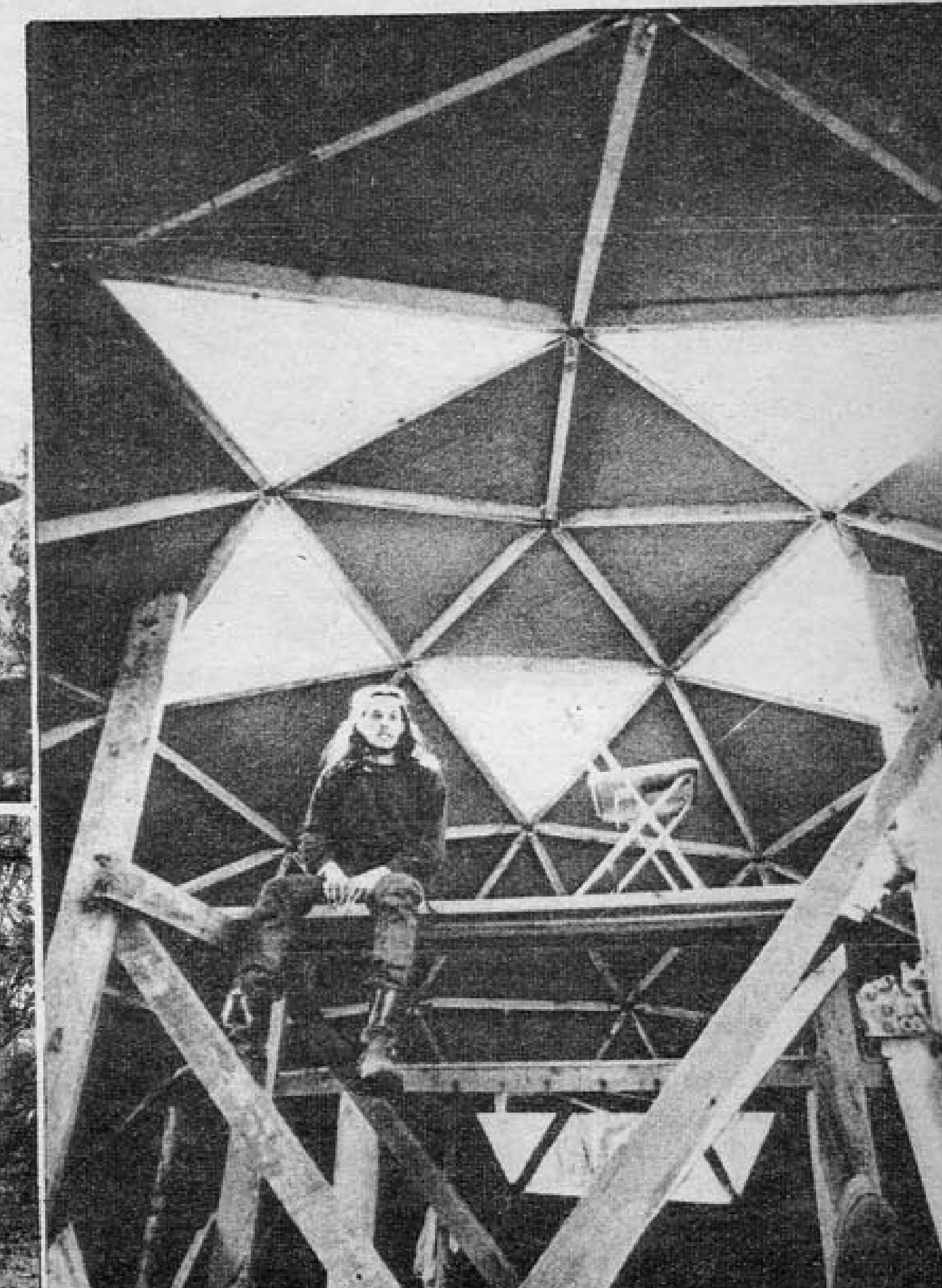
A 24 ft dome was constructed by Charles Scaff, an Ananda resident, following the same pattern as the kitchen dome only skinned with fiber board. We had planned to skin the dome with Armour Shell, a flexible membrane that will be described in the section on Icosa Cabins. We thought that since we needed to take into account snow loads we would put 1" chicken wire underneath the Armour Shell. This proved disastrous since the chicken wire over the struts would tear the Armour Shell as it was stretched over them. We then decided to try Kaiser Firtex Insulation Board ½" thick. The fiber board is less expensive than plywood, has insulative quality and is protected from weathering on one side, though it definitely needs further surfacing. It is now a toss up whether the chicken wire adds any strength or not. Jay thinks that it is too flimsy to help. Anyway the dome has survived snow loads.

An experiment was tried using a relatively inexpensive sealer. It was reasoned that if it didn't work—the only real test is on the dome itself—then composition shingles would be used. Plas-t-cote, fibrous aluminum (trailer top coating from the Elixir Corporation, Gardena, Calif.) was obtained at a local trailer supply store. This was rolled and painted on over the seams. After the first rain more was brushed on over the leaks. So far there haven't been any more leaks, but only time will tell. Asphalt felt was cut in small circles and stapled over the hubs and sealed with the Plas-T-Cote. The manufacturer says that Plas-T-Cote has "soundproofing and insulative values."

A beautiful entranceway was created under a hexagon. It is large enough to hang coats and take off boots and is built in a conventional manner using 1 X 12's and roll roofing on top.



Icosa cabins



24' Pacific dome

## Icosa Cabins

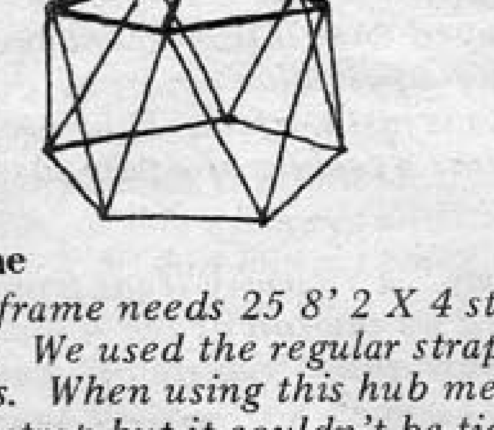
### Introduction

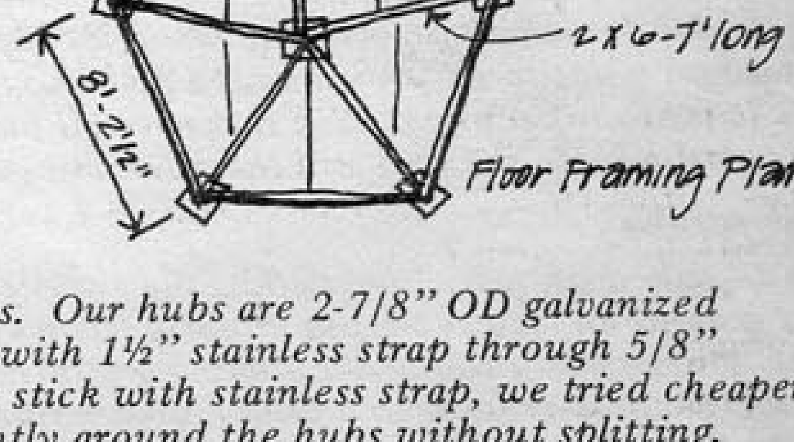
One of the needs of the Retreat is to provide adequate housing for the retreatants who come here to study and worship. 10 X 12 tents have been in use for the past few years, but but they are now in badly weathered condition. Furthermore, people are coming here during the winter when tents are out of the question. The nice thing about them has been their size. They are perfect for one or two people for the few days to a few weeks they spend here. Inexpensive, all weather cabins of about the same floor space are needed to phase out the tents. Since a regular dome is too elaborate for this need, the basic Icosahedron with no breakdown has been our replacement choice.

Since this decision many fine things began to fall into place. We discovered that a conventional roof with no sealing problems is possible. It can even have overhanging eaves. As we began to plot out its size we found that by using 8 ft struts the triangles contain 28 sq ft, so conventional 4' X 8' material is easy to use.

### Platform

For the platform use the basic radial model. We used 5 cement tier blocks and one large flat rock for the center as our foundation supports. Cedar posts were cut from the forest and used for the uprights with a particularly large one for the center post. 5" diameter posts are good for the perimeter uprights (or a 4 X 4) and an 8" diameter post for the center. We used 95 ft of 2 X 6's, 5 for the 7' poles, 5 for the 8'2½" perimeter joists and an assorted 15' or so for the 5 other joists. 1 X 6's were used for the decking. I recommend, if you have the money, to always use tongue and groove stock for the decking. Run the decking parallel to one of the sides. We used regular asphalt building felt as a vapor barrior between the decking and the joists. Place the extra 5 joists in the basic pattern shown in the diagram. The actual placement isn't critical. They should be fairly evenly spaced to support the decking and perpendicular, plus or minus 15°, to the pattern in which the decking is laid.



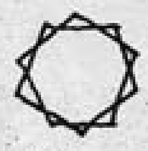




### Frame

The frame needs 25 8' 2 X 4 struts and 11 hubs. Our hubs are 2-7/8" OD galvanized pipe. We used the regular strapping technique with 1½" stainless strap through 5/8" holes. When using this hub method it's best to stick with stainless strap, we tried cheaper iron strap but it couldn't be tightened sufficiently around the hubs without splitting. The nice thing about the Icosa cabin is that all the struts are the same length with the same angle of 31.7°.

The best method for erecting the frame is to build the top pentagon with the hubs and perimeter struts attached. The roof supports should be nailed in at this time. They should be somewhere in the middle of the triangle, depending on your skylight window pattern, and parallel to the perimeter struts.

*The base triangles should be laid out and fairly well secured in their probable position. The tops of these triangles will be without their hubs and can be tied together with rope. They are ready to catch the top pentagon assembly when it is set in place. The trick is to put the base of the side triangles underneath the top pent with the hubs of the pent bisecting these struts. In other words the top pent over the platform forms a ten pointed star.*

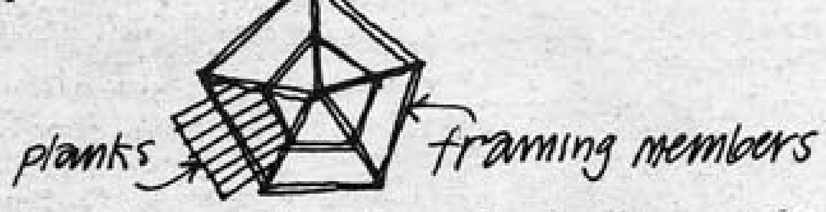


*Now with the help of five strong friends the top pent is picked up, set in position and strapped into place.*

*Please note: we did not strap in a base triangle strut but cut the side struts with a bevel and toenailed them into the decking. We cut the struts for 4 Icosa cabins at one time and put up all the frames before finishing one completely. This was a mistake. Had we put the siding on one before putting them all up we would have made a startling realization. Without the base struts and hubs the ten side triangles can be off a bit, that is, not perfectly equilateral. If they are equilateral, like they would be with all the struts strapped on, then it is possible to pre-fab all the siding or paneling before proceeding to the roof. 9" diameter circles cut from plastic or asphalt felt should be stapled over the five base hubs of the top pent. This will help make the cabin air tight. Screen can be used if you want these hubs to be permanent vents.*

### Roof

*One triangle or more that is formed by the struts and the roof supports can be left open for a window. For most of our windows we used 15 mil ultraviolet resistant vinyl (outdoor Type Formulation A/B, Goss Plastics Film Corp., 3610 S. Broadway St., Los Angeles, 90007; 15 mil, 150 lb roll, 54" wide about 75 dollars). 1 X 6's were used for the roof planks and are right for the job. They were laid at right angles to the perimeter struts of the top pent.*

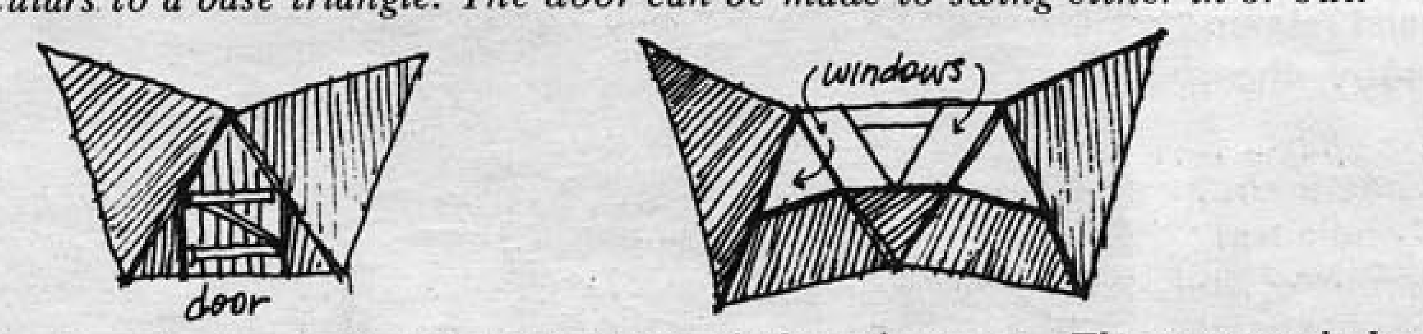



*John Parmley noted that it is quicker and easier and actually more beautiful to make a full pentagonal skylight because then a large number of roof planks have square edges on both ends of the board. It takes John less than a half a day to cut and fit all the roof planks. The planks are allowed to extend so that there is a foot or so overhang. Once the planks have been nailed to the struts, a 2 X 2 strip is nailed underneath the overhanging planks. The 2 X 2 keeps it flat and free from wobbling when the roofing paper is laid out. Some flashing of roofing paper, asphalt felt, plastic or metal should be placed between the gap formed between the planks at the base points of the top pent before the roll roofing is put in place.*

*We used 90 lb roll roofing which we rolled out and tacked down with roofing nails. Lap cement was used under the laps. Allow a ¼" overhang of roofing paper, this prevents water from being absorbed by the exposed edge of the roof planks. Start putting the roofing paper on from the base and work to the top to get a watertight shingle effect. Be careful to roll the paper out flat. Note most everyone uses too many roofing nails and too much lap cement. If you have a vinyl skylight, it should be put on before the roofing, that is, the vinyl should be between the roofing and the planks. The skylight can be easily sealed by putting lap cement between the roofing and vinyl. In this case more cement and nails should be used then on the other laps. The more standard way for windows is to put the vinyl over the roofing and then nail battens on to secure the vinyl. None of our skylights have leaked and since they are small, never an altitude of over 3 ft, they can take a snow load.*

### Windows and Doors

*2 X 4's are used to frame in the windows and the doors. The door is made by dropping perpendiculars to a base triangle. The door can be made to swing either in or out.*



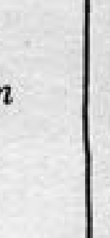

*A very pleasing window pattern is with three windows in a row. The center window can be made to open and close. We made this window smaller by running the 2 X 4 frame parallel to the struts and hinging it at the top.*

### The Bevel Gauge

*The builder's best friend at this stage of the game is the trusty bevel gauge. This is necessary because all the 2 X 4's needed for framing in windows and doors have compound angles. A short picture course in finding these two angles:*

*The most important trick is to make sure which length you are measuring and to be consistent in relating the angles you are finding to that length. If you have never done this before then it is a lesson in patience. It usually takes cutting a few too short and backwards to catch on. Even though we made mistakes we miraculously found a use for all the wood.*

### Siding



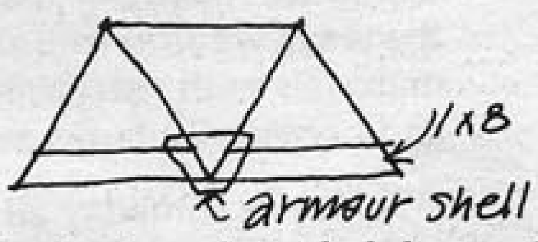
*On two of our cabins we used wood for the siding. We used rough-cut 1 X 12's on another. These were shingled over each other. On the next ones we'll do like this, we'll use ship lap stock.*
*The trick is to build a 1 X 2 frame on the 5 triangles with their bases down. The siding is then placed across these triangles first. Next the siding is placed across the triangles with the base up. The siding of the base up triangles is cut longer than the siding for the base down triangles which allows the siding of the base up triangles to be "shingled" over the siding of the base down triangles. Vince Mow dubbed this the "inset overlap method."*

*Standard Oakum pipe packing material can be stuffed into the cracks if necessary. It looked like we had to do some packing on one of the cabins but the "inset overlap" prevented it from leaking. With ship lap stock there would be no cracks.*
*When starting from the bottom up make sure the first board extends below the edge of the decking.*

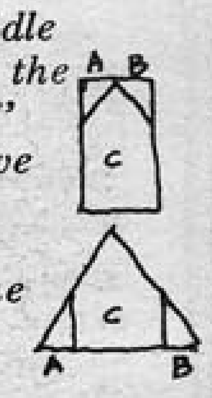
*We put reflective metallation between the struts and the siding. The reflective part faced inward. The paper forms a moisture barrier and reflects heat back into the cabin. Rigid foam panels were used for insulation over the reflective paper.*

*On some of the cabins we used Armour Shell L-10.( We got from Bill Roberts, Cooley Inc., 7300 Artesia Blvd., Buena Park, Ca. 90620). The construction of Armour Shell L-10 is 22 X 22 210 D. nylon sandwiched between a layer of .004 mil PVC on each side. It cost $1.16 per yard and comes in 50 yd or 100 yd rolls that are 54" wide. I understand that the awning industry has been using this material for years and that the army is now using it in place of some of its neoprene items because it is much cheaper. As an inexpenxive, durable, flexible membrane it's hard to beat. There are stronger products by other manufacturers but they are more expensive.*

*To get the maximum coverage with Armour Shell we cut the roll into three 50 ft lengths and cut one length in half. By sewing a half and a whole together we got enough material from a 50 yd roll for two domes. We used nylon or waterproof thread and tried both the French seam and the Flat Felled seam. We preferred the latter. The heighth of the triangles in 95 inches and the width of the Armour Shell once seamed comes to about 80 inches. To make up for this difference we nailed a 1 X 8 around the base triangles and stapled in a piece of Armour Shell (that came from cutting out the windows) on the triangles with their top down.*




*The Armour Shell is stretched over the struts and stapled down. Be sure to stretch it out evenly. Battens are nailed with caulk underneath over the Armour Shell at the struts. This prevents any possible leaks that may occur where the staples cut through the material.* Please note: *If you use a flexible membrane for your siding, put it on before you put on the roof. In this way you have the top 5 struts as a surface over which to stretch the membrane.*



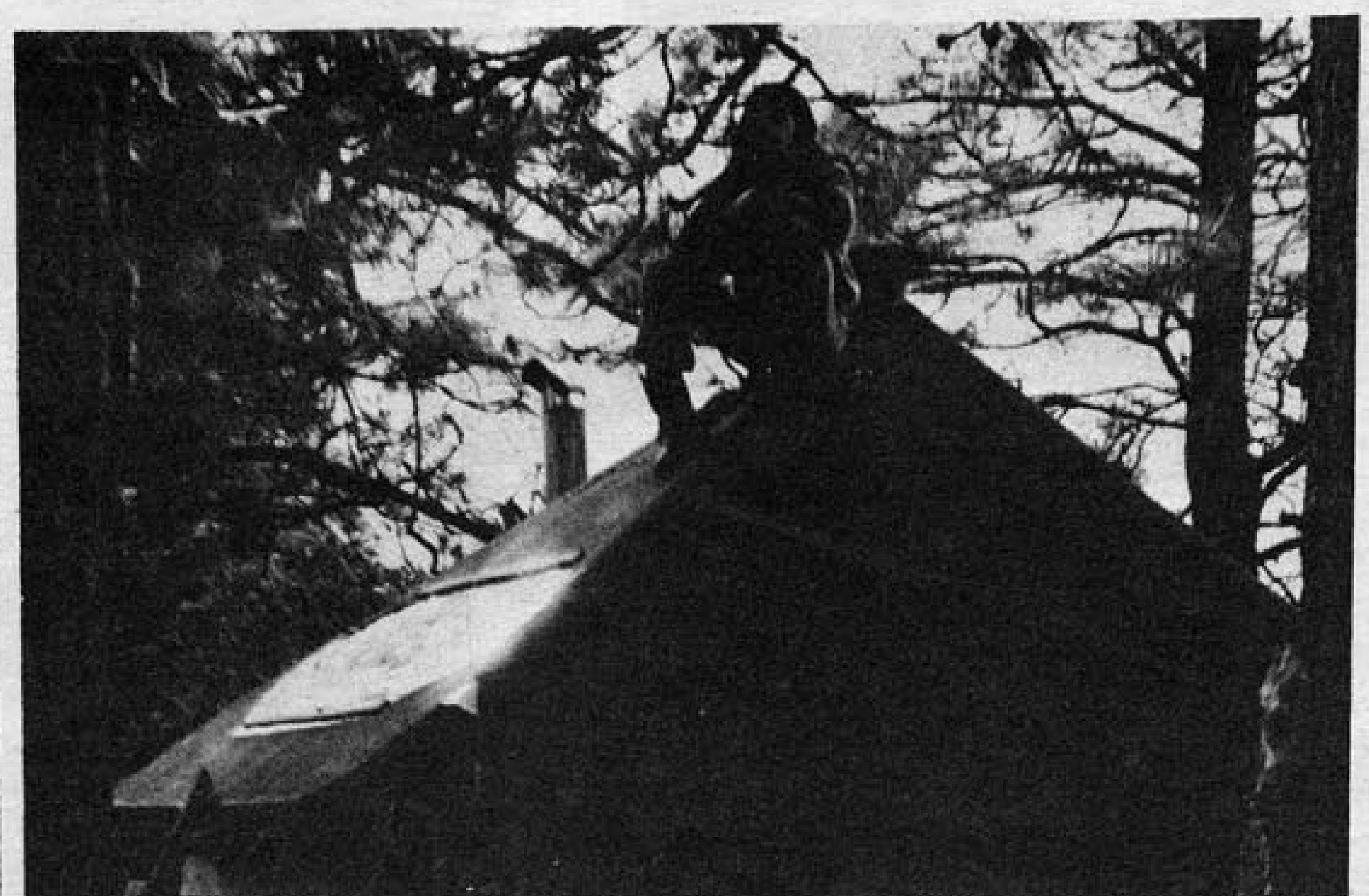

*Since we now had a flexible outer wall we thought we'd put in a rigid inner wall. We bought some cheap paneling. It was cheap because it was off size 4 X 7 but this was perfect for us. We then had to frame up the triangles for the paneling. The handy bevel gauge was necessary. If you strap in the base triangles then all these supports are the same size except that there are both right and left hand models. Make sure the models work. They must be placed on 4 ft centers and must be centered in the middle of the triangles. The 4 X 7 material was then cut to fit. Molding can be nailed over the inside struts to give it a nice neat appearance. On one cabin we stapled in regular 3" fiberglass insulation between the struts and framing. On another we put up reflective metallation on the outside before stapling on the Armour Shell. We are still in the process of finishing this one but we don't think we'll have to use any more horrible fiberglass insulation. The cabins are so small they are extremely easy to heat and the dead air space should be sufficient insulation. The main thing is to make sure the cabins are air tight and free of drafts. We are now able to get some seconds on inch thick foam matting to insulate the floors.*

*It would be easy to do plywood on the exterior. 4 X 8 sheets should be used in order to fit over and extend down around the platform. The triangles could be framed the same way as for the interior paneling. Or, the plywood sections could be put together using corrugated fasteners without any extra framing. Fiber board could also be used in this manner and if you want you could stretch chicken wire underneath as described in the section about resident domes. Roll roofing could be used as siding over the fiber board and then there would be no further need for insulation.*

### Concluding Thoughts

*This simple Icosahedron is an excellent inexpensive cabin. It costs about $155. It's quick and easy to build. It has too little floor space to come under the standards of the Uniform Building Code, though structurally it is certainly as sound as any building that the Code deals with. You can put this up in the summer, live in it and save money during the winter. The following year build a larger dome. The Icosa can then be converted into the kitchen, the kids' room, a meditation room a work shop, the bathroom, etc. Basic Costs:*

| | |
|---|---|
| $30 | Platform |
| $20 | Frame |
| $25 | Roof |
| $40 | Windows and siding (wood and Armour Shell are about the same in cost) |
| $40 | Insulation (rigid foam or fiberglass and paneling are about the same in cost) |
| Total: $155 | |

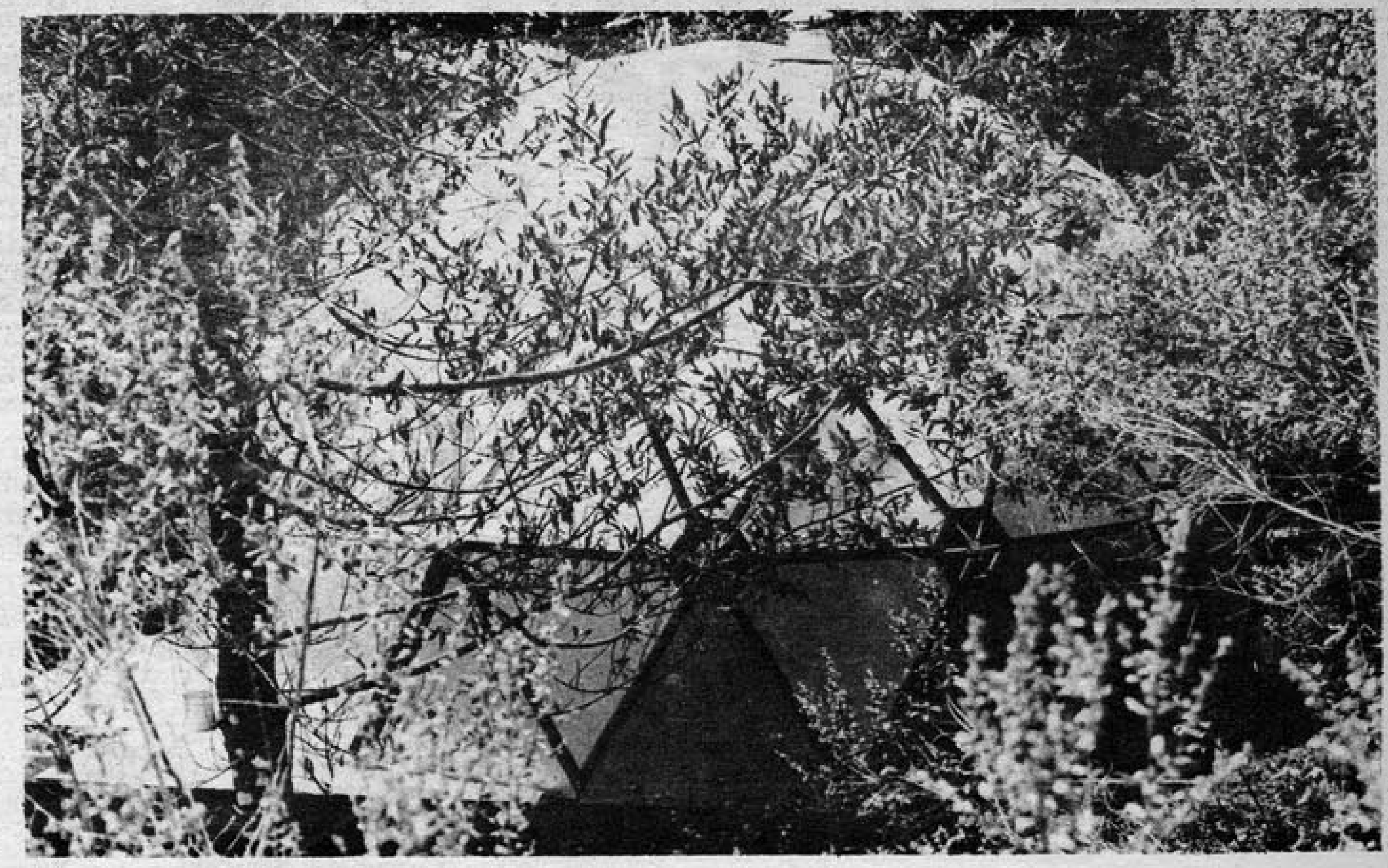


Alan and Heath have gone from a tipi to a plastic-metal dome, to experiments with fiberglas, plastic foam, and wood. We are reprinting portions of Centering, written by Alan and Heath last year, along with their current feelings and ideas after a good deal of experimentation with different building materials.

Before moving into our dome, we lived in a 16' Sioux Tipi. I spent many weeks hunting down the poles in the woods surrounding our area. The tipi sold us on the idea of an undivided circular room with a symmetrical open ceiling coming together at the top. Along with the igloo and yurt, the tipi is an original shape. The mobile Plains Indians perfected its design. It is the architecture of motion. It is made up of triangles that can be collapsed and dragged on its struts (poles) behind a horse. The greatest advantage of a tipi is its portability. As we get farther along with domes, we find more avenues to increase the portability (if one so desires it) of domes.

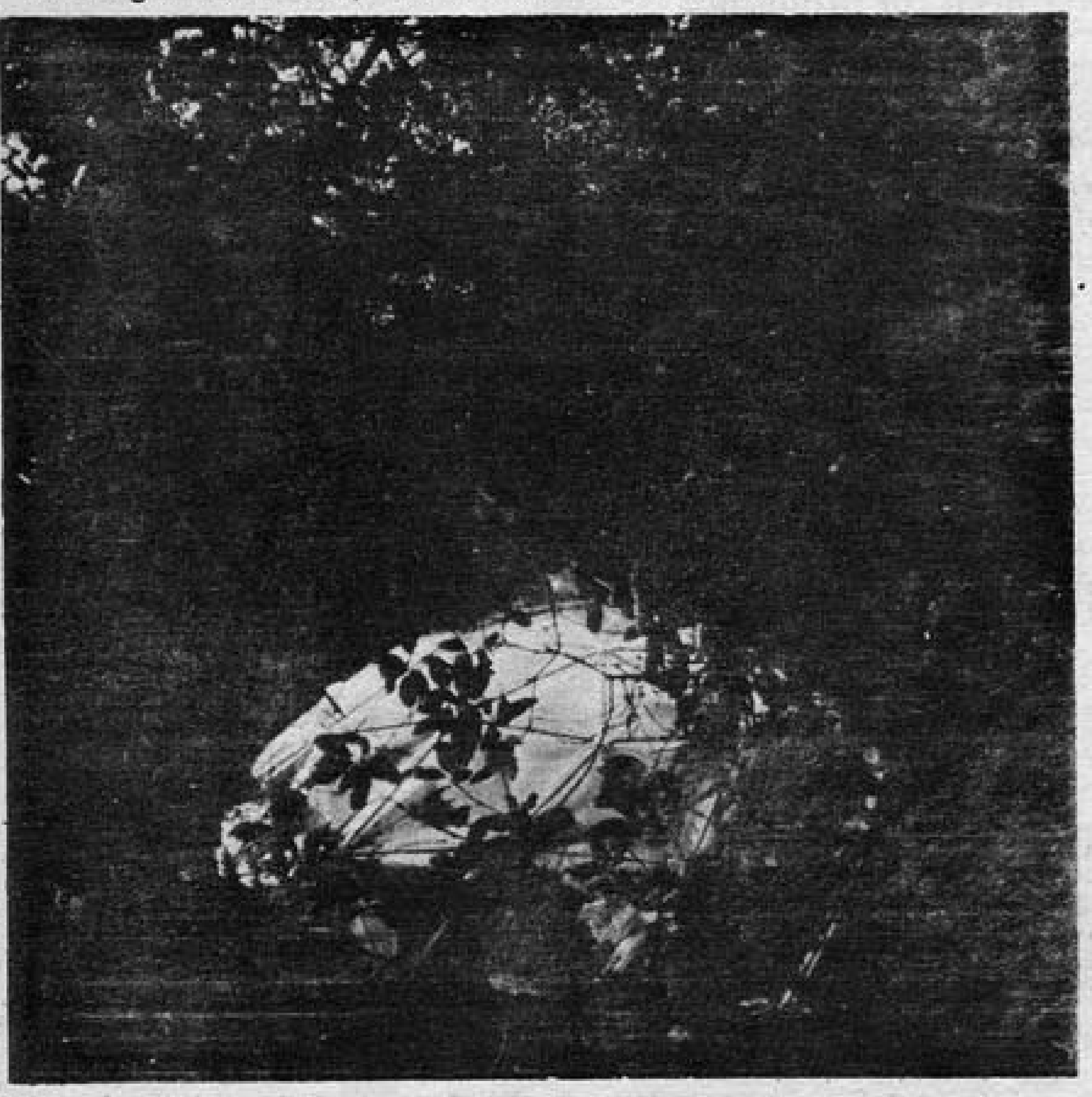
The question of the choice of materials in our present day comes up in many contexts. In choosing materials you should respect them. The materials should be treated as something sacred, something we have been given to be transformed into something else. The more sacred we make our materials the more interesting become the ways we find to use any leftovers. By treating our materials with reverence we treat ourselves with respect and necessarily build good vibrations into our dwelling.

Maybe someday all our buildings will become temples.



Windows and ventilation are two more basic questions. Fuller says it's good to have a window or so at ground level. We reserved this spot for our altar. It's good when designing a dome to plan to have an altar or special place along one section of the side, preferably in the east. Also, make sure you plan to have sufficient openings for adequate ventilation. It's easy to figure out a way to have at least one top triangle hinged and have it open via a big spring.

Besides the main entrance in the floor we have two side triangles that open onto the platform (our balcony) and two small openings in the back that are just above the ground for the dog to enter and for us to pour out our biodegradable soap water and leftover tea.

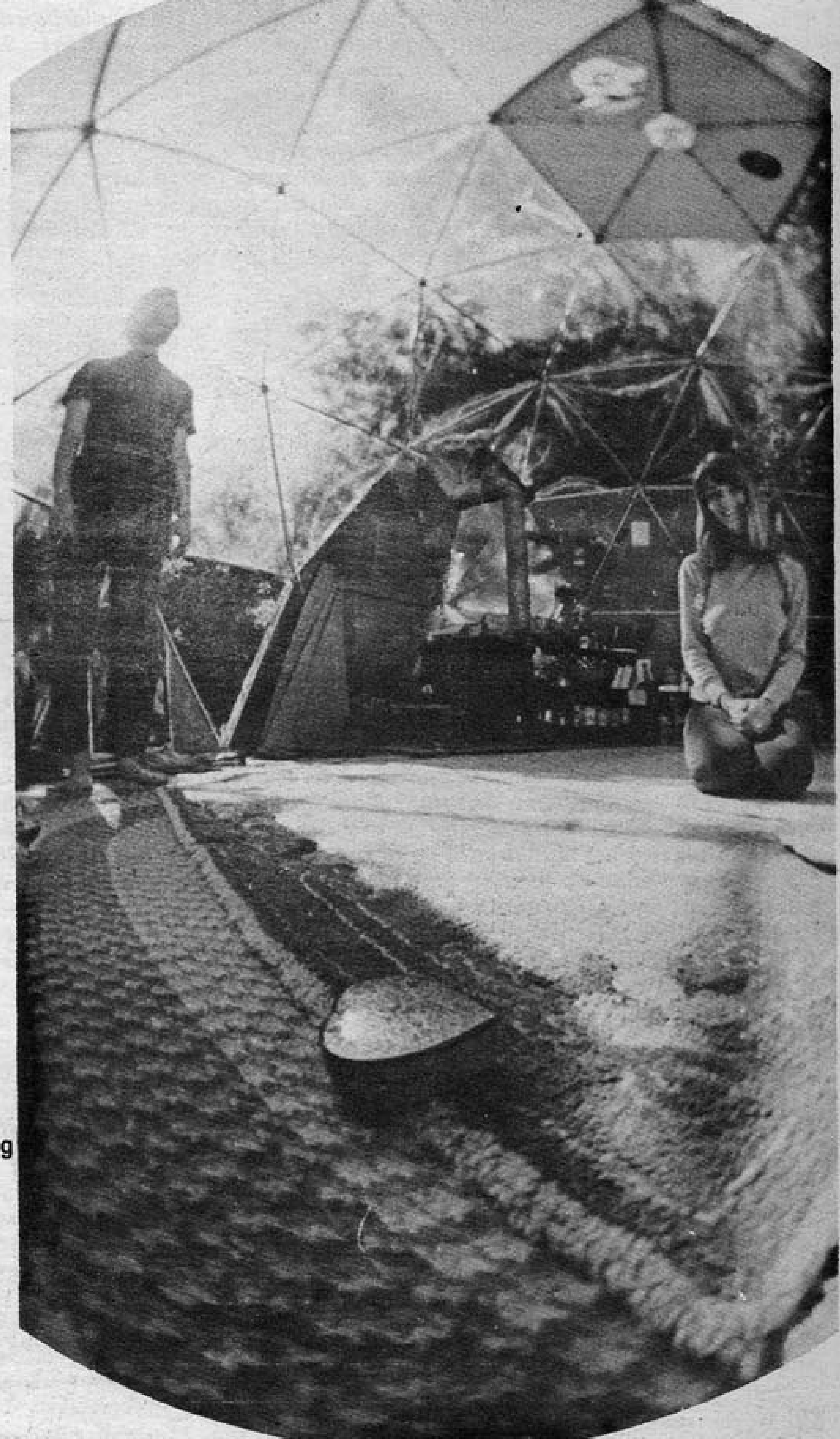


A few of the questions concerning plastics are that we have to consider the pollution caused by their manufacture and presently plastics are only produced by larger industry. There is, however, much room for the small craftsman on many levels. A hidden advantage of the use of plastics is that since internal combustion engines must be phased out, the big industry and investment behind petroleum will still have a place to work before a whole other phase takes over when the earth runs out of petroleum. A few more general considerations concerning petroleum: obviously we shouldn't pollute our ocean in trying to obtain it; also, sucking it out from under the earth's crust may contribute to future earthquakes.

We planned the layout of our dome in correlation with its intended use. Our bed is up about 5 1/2', with storage underneath and the stove and kitchen are up against the sides. The floor is left open—a large open area for work, play and yoga classes. Our classes are incredible. Domes are such a centering trip. One's eyes can easily center on any of the mandalas formed by the struts.

Even our conversations are more centered because we sit in a circle and stay in closer touch with each other. All vibrations—sound, light, heat and all our awareness -begin in the center and radiate outward and rebound back and forth from the center. Consequently, chanting is mind-expanding and all-encompassing.

Living in a spherical single unit home makes us wholer people. We feel more whole and have our whole trip around us. We stay more in touch with each other and our friends and also this wholeness has a healthy effect on our possessions, our wants and desires. Feeling whole and centered is crucially important, and domes surely can contribute to this.



**Conclusions** *Looking over what I wrote for* Domebook One, *I realized that our excitement and enjoyment with domes has only increased after another year of dome work. We have however made one basic reversal in the year. In the future we've decided not to live in a metal frame or metal skinned dome. Both my wife and I feel that the metal steals vibrations from us and creates an artificial magnetic field around us which removes us rather than extends us into our surroundings. Now I don't consider this a heavy criticism. I doubt if it will have much effect on other builders. I only suggest that for buildings used for meditation or homes for yogis it would be best that metal be used only minimally, for example, in the hubs.*

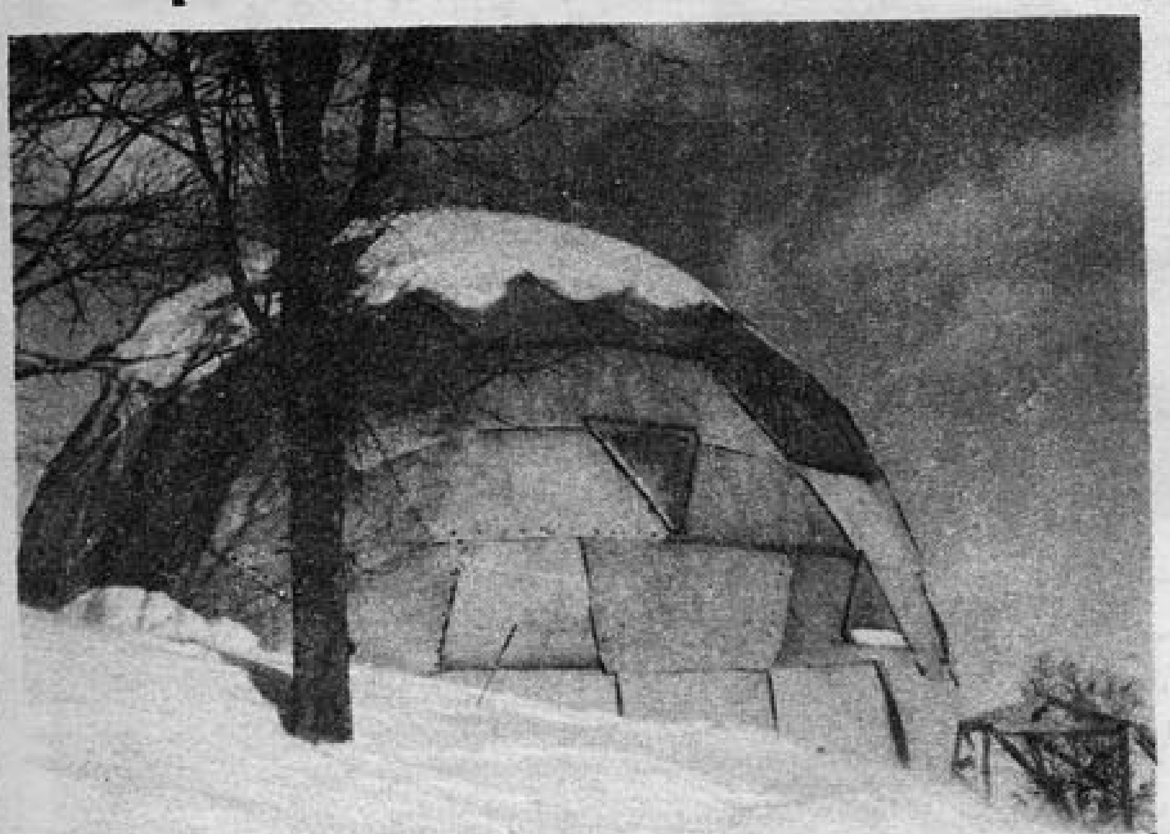
*The questions raised last year about plastics and the pollution caused by their products is still open to consideration. After working with more wood this year and experiencing the feel of obtaining wood from the local forests and neighborhood saw mills and seeing properly managed forests, I feel happy about working with wood. As builders we have to be committed to good healthy forest management practices. However, we have to also realize that even if these proper practices were in effect all over now, there still would not be enough wood for all the new housing that will be needed in the future. Consequently, we must further be committed to the exploration of other possibilities, like plastics, foam, metal, cement, ceramics and earth preparation. In exploring these new avenues the additional necessary work also has to be done so that the pollution caused by their production and destruction be brought down to zero.*

*Bliss and Joy to all dome builders. Give the fruits of all your actions to God. Om Shanti.*

Community planners
Ananda Domes
Alleghany Star Route
Nevada City, Ca 95959

# writers

## 6 FREQUENCY ICOSAHEDRON TRIACON DOME



*Our project was to house a comunitity in a land where several months of each year must be spent in a controled invironment.*

*The first thing we did was to sit down and make a list of all the things we would like to have indoors, and how much floor space would be desirable for each.*

*We cut pieces of graph paper representing the space requirements and fit them into circles representing possible leavels in various sizes of domes untill the size required was assertained.*

*We later decided that instead of putting everything in one dome we would make two smaller ones; one for noisey activities and one for quite ones.*

*The building of the first of these is a story that can be told.*

*Taking into consideration the various dimensions and strengths of the available matereals we decided it would be a 42' diamater six phase icosahedron triacon.*

*Before anything else we build a scale modle out of pieces of aluminium tubing, flatened at the ends and bolted together.*

*Our location was to be a hillside facing the path of the sun.*

*The hillside was dug away to facilitate a kitchen, food storage, coat room and tool shed below the leavel of the dome.*

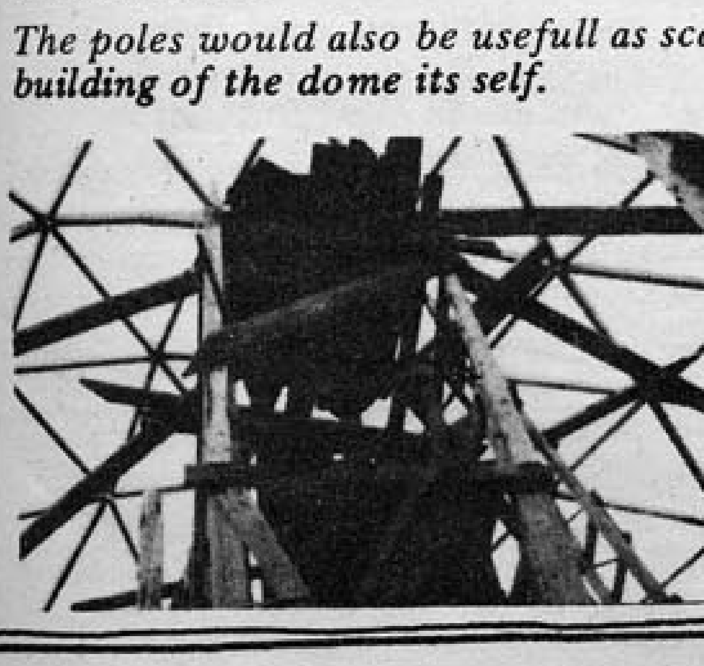
***For the foundations we used logs from an old log barn.*** *These were treated with creasote and set into three foot (give or take) holes on top of some stones and a couple shovel fulls of concrete. The rest of the hole was then stuffed with concrete and stones.*

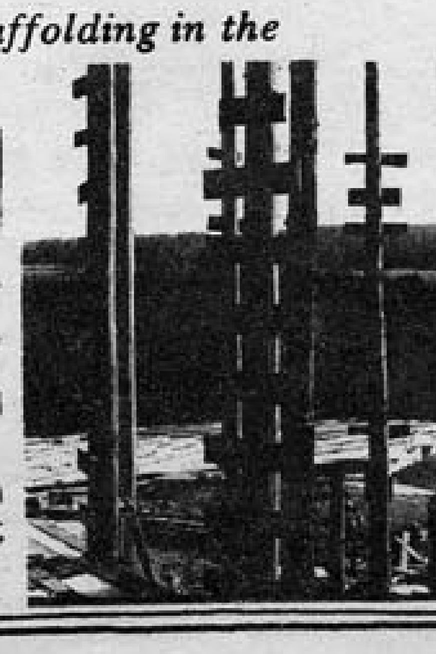
*To stand up the tallest poles, three ropes were tied with a big loop (so that they could be removed by slipping them down the pole as compared to climbing up and untying them.)*

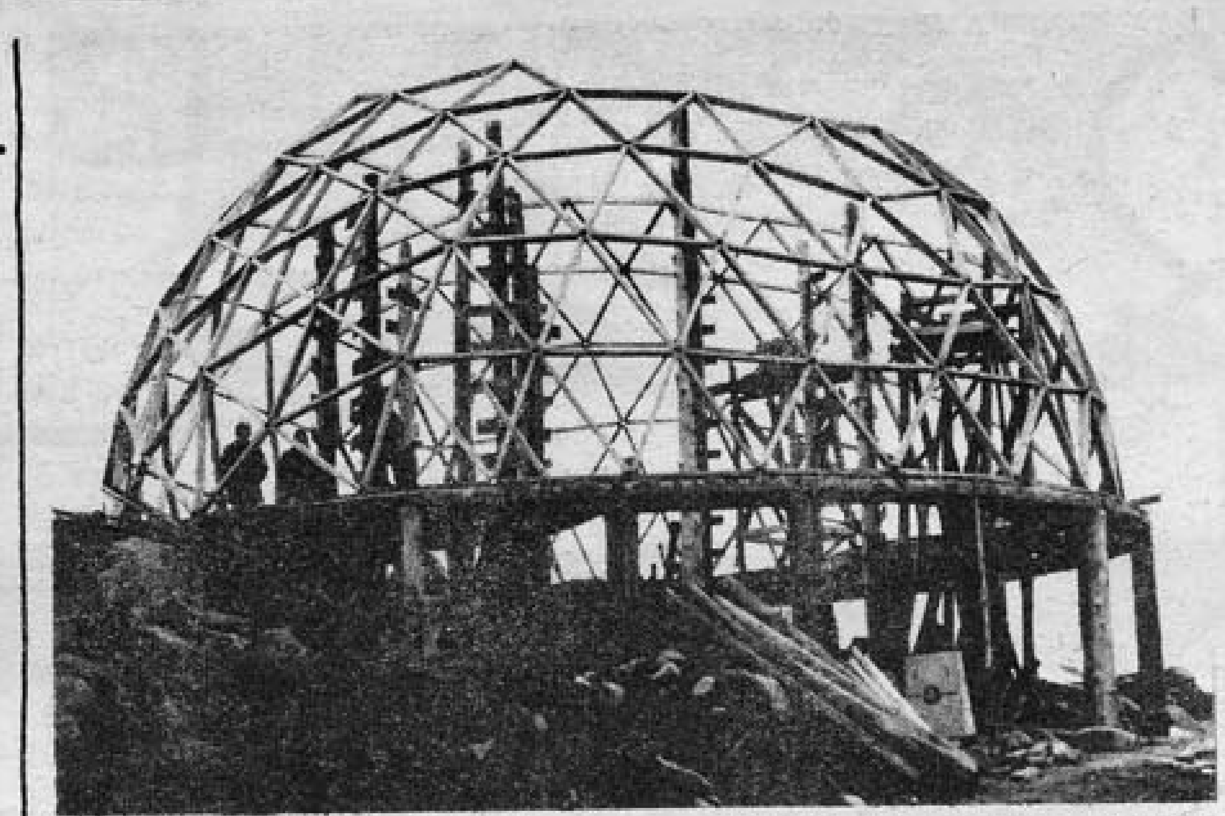
*A wide board was put in the hole opposite the butt of the pole, and another laid on the ground on the pole side of the hole, these were to prevent the hole from caving in too much when the pole started to move. Then with one person guiding the end of the pole, three or four lifting from the top end working towards the hole, and one man on each rope, each pole was erected and lowered into its hole. They were then held uprite by the ropes going in different directions untill a couple of bords were nailed between them and near by posts that were already solidly set...*

*Poles allow one to build floors at any height and in any direction that they might be desired.*
*A one foot change in floor leavel can make a functional distinction in floor space without retarding any form of comunication.*

*The poles would also be usefull as scaffolding in the building of the dome its self.*







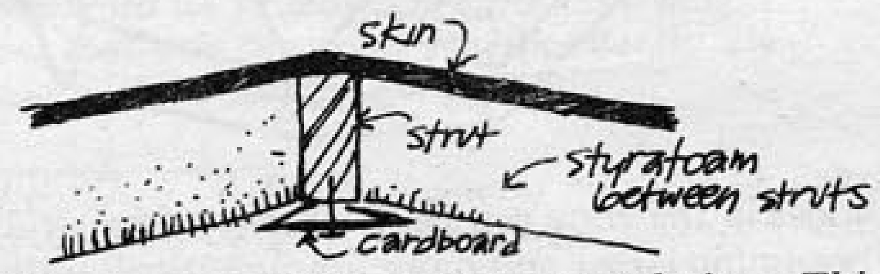
***The construction of the frame was 2 X 4 strapped to schedule 80 Poly Vynal Chloride (PVC) piping.*** *We had intended to stuff the pipe with blocks of wood, but with the frame up, almost no distortion was evident so we passed that step up.*

*Our skin was scrap industrial canvas laid on a layer of cardboard to prevent sagging when it was put on. The pieces of canvas (we found 3 tryangles at a time to be optimum) had 4" overlaps where every one was on top of another, and the bottom row went from the dome to the edge of the platform to facilitate run off.*

*The canvas was water proofed. The overlaps and nail holes were sealed with a roofing compound.*

*Windows were clear polyethelene held on with strips of wood and sealed on the outside with roofing compound.*

*The inside was insulated with scrap styrafoam held in place with strips of cardboard folded for rigidity.*

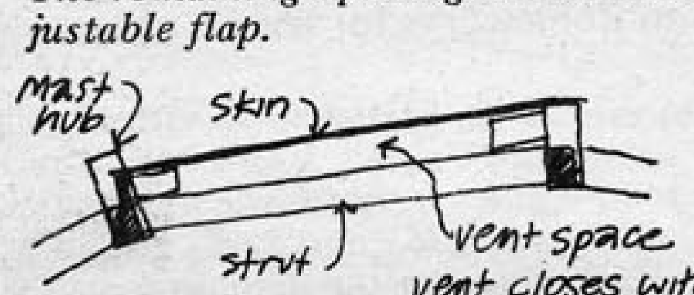


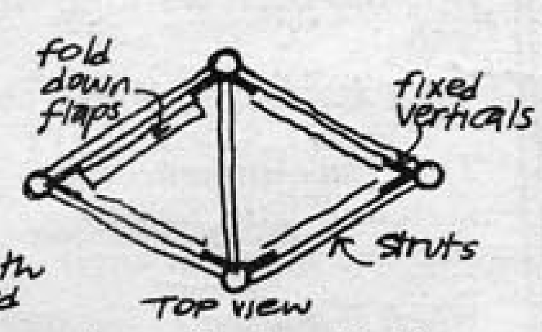

*At the top of the dome we left a hole for ventelation. This we covered by using over sized hubs for the four sorounding joints.*

*About .75 ft. above the dome proper, we constructed 5 members of a larger dome over which we put a skin to keep out the rain.*

*The space between the two layers of dome was then sealed at the corners with pieces of canvas.*

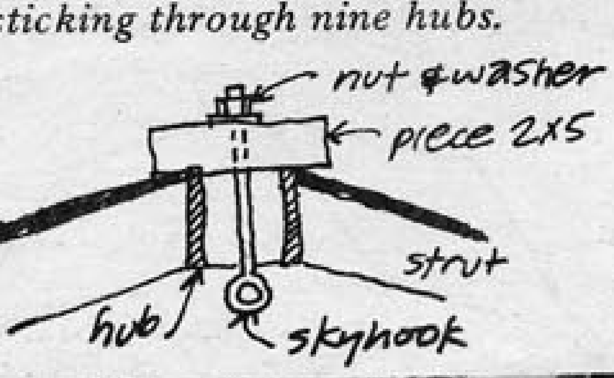
*The remaining opening was then accounted for by an adjustable flap.*

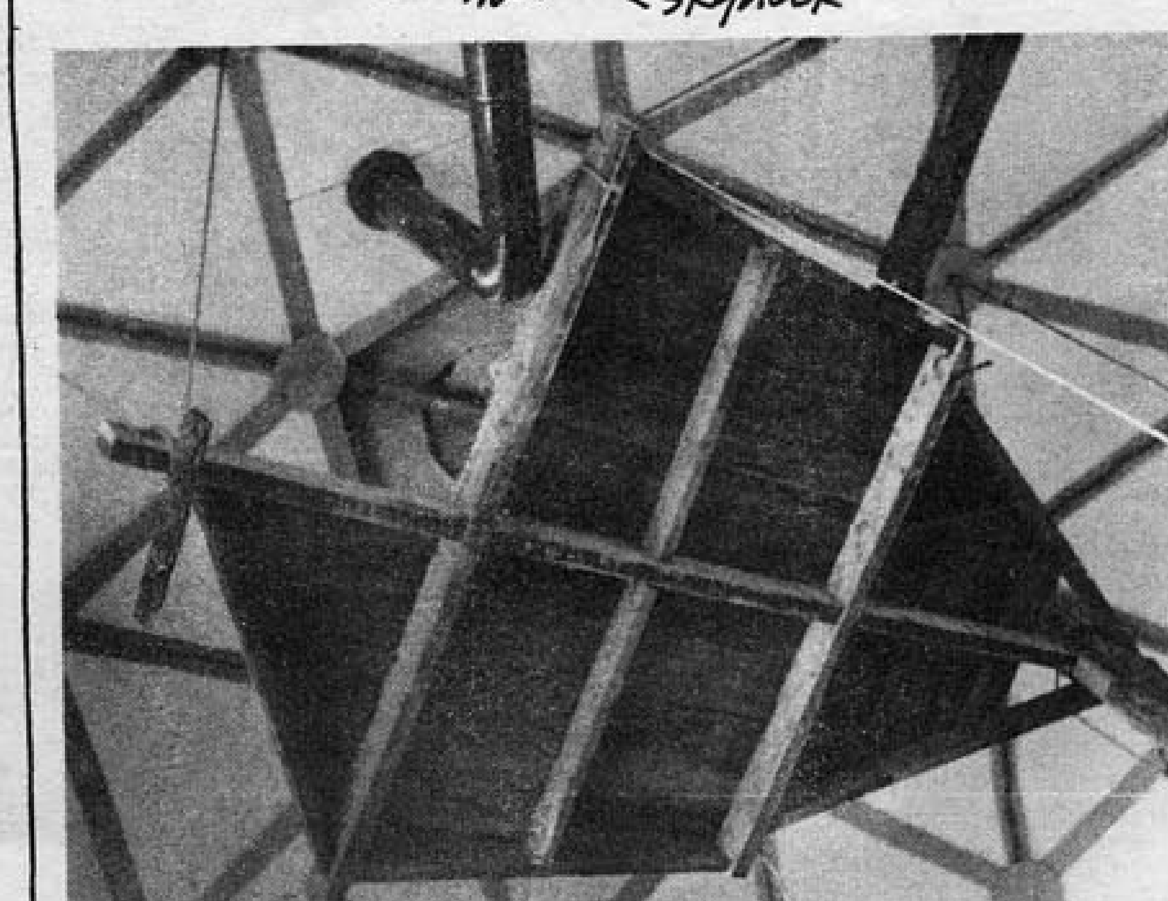



*When the flaps are down, one can see for miles by sticking his head through the vent hole.*

*To enable us to stand with our heads out the vent hole, and also to take advantage of the ecoustics at the top of the dome we built a platform. One corner is tied onto one of the posts and the other five corners are hanging from nine ropes tied to skyhooks sticking through nine hubs.*



*We have yet to build the kitchen floor and a loft. When those are done, the space on the crescent floor under the loft will be partitioned off for private spaces. These partitions will be hanging cloth so that when one wants privacy light is stopped, and sound absorbed. If one dosen't want privacy the partitions can be rolled up and tied out of the way, or just pulled to the side and tied.*

*I hope this arrives in time for your second edition...*

*...If you should have a pile of money lying around, we're broke*
*but don't feel obligated, information should be available to anyone free of exchange.*

WITH YOU FOR PEACE
MIKE NICKERSON
MORNING GLORY, CANADA

## MARSHMALLOW TECH

*Gentlemen: The dome is coming! Soon the whole country will be involved in the study of structure. I'm 22.*

*I've read your book* Domebook One. *I've been working on domes since January, 1970. Now I have some suggestions for you...*

*Take some miniature marshmallows and stick toothpicks into them. Make a triangular grid on a flat surface. Then make it 3-dimensional by raising tetrahedrons. You will see that if you put a tetrahedron on every triangle that their vertexes will be too close together. You must put a tetrahedron on every other triangle in order to make a space grid with all members equal. However this structure is not perfectly stable because the tetrahedrons are connected on their edges. What is desired is to connect them on their faces. This however is impossible, just look at the icosahedron. It is the nearest thing to it but icosahedrons will not themselves fit together. So it seems wrong that such a simple imaginable, and desirable thing should be impossible, but I guess there is no such thing as a completely stable space grid. However the one I described can be used to make walls, floors, rafts, anything. Idea: assemble a raft on the water from logs and "star joints" then build a dome on top of it. Problem: the bottom of the dome must be made to coincide with the grid of the raft. Does such a coincidence exist?*

*Internal structure is the answer to insulation.*

*Large round helium or hot-air balloons should be harnessed by geodesic net made of rope...*

*My paper domes I make by gluing 4 sides of a stack of paper while squeezed in a press. When glue is dry I drill little holes in a dome pattern on drill press. Peel off 3 at a time, draw the cuts and crease the folds, cut out.*

*Let me tell you, there is no end to the possibilities of curved and space-grid structures. Man should have had the dome in the beginning, not the end. I rank the technological discovery of spherical construction with fire and the wheel. I can't understand why nobody invented it until now (1950). It's so obviously simple and desirable. And why didn't Bucky Fuller ever publish dome-building information?* **The world's millions need the dome.**

*Look at the cover of Life magazine, April 28, 1967. Expo dome: the hubs are obviously "star joints" as I have described and the struts are tubes. Why did you not copy this design? You need not be burdened with staples, nailing, straps, and squashing tubes—all unsound techniques.*

*The simplest models are flat toothpicks glued together. Then glue 1/8 dowells. Tedious. Then soda straw domes, actually easiest if they make the joints available.*

*After domes and cylinders: parabolic towers (like the Eiffel), parabolic reflectors, direct harnessing of sun's energy. Huge aircraft fuselage.*

*Model idea: heavy plexiglas triangles, milled to the precise angle on the edges, glued together into sphere or dome.*

*P.S. The fundamental model is a ping pong ball with icosahedron drawn on it. Get them for under $7/gross from Athletic Trainers Supply Co., 427 Broadway, N.Y. 13, N.Y.*

***You can drop a box of star joints from a plane and the person on the ground could build a dome from logs in the forest.***

*Natural dome: steel star-joint hubs, cedar pole struts. Then wrap vines around from bottom to top. Tie vines to struts. Then thatch the vines. Only trouble: it'll burn.*

*The sphere will be used for space stations.*

*The sphere will be necessary before we invent the way to make ourselves independent from gravity with some kind of gyros and things. Look at how the angels moved in Ezekiel 1...*
*I dare to say: When structure becomes recognized along with cycles of rhythm as the basis of the physical universe, man will be on the way to unlocking the secrets. The dome will be the take-off point for all scientific research.*

*Consider: A popular song or catchy tune may be described in terms of the individual notes and beats: any given note or beat is repeated in a steady rhythm within any given pattern of notes and beats within the song. Likewise the patterns have their cycles. Using a computer you could decipher any song and print a different sheet of music for every member of an orchestra, all for the same song (good test of sight-reading music). And so it is with the entire universe. If you look at any given event you will see that it repeats itself sooner or later. If man can become aware, perhaps through a combination of observation and intuition of the rhythm of the universe, he will truly "have it easy." It says in the Bible "Day to day pours forth speech, and night to night declares knowledge. There is no speech, nor are there words; their voice is not heard; yet their voice goes out through all the earth, and their words to the end of the world."* Psalms 19: 1-4.

*All this can come about only if man respects the universal law of Love by which all life must abide. Indeed, man's future may hinge on this more than on his technology. It was written long ago: "The earth he's polluted under its inhabitants; for they have transgressed the laws...all joy has reached its eventide." Man can choose whether this will be a prophecy come true or a warning well-heeded. Look around you. Who is working? We have been warned "Why do you spend your money for that which is not bread and your labor for that which does not satisfy."* Isaiah 55: 2.
*Man's technology has its limits: "...the way of man is not in himself"* Jeremiah 10: 23, *and "Woe to him who strives with his Maker."* Isaiah 45: 9.

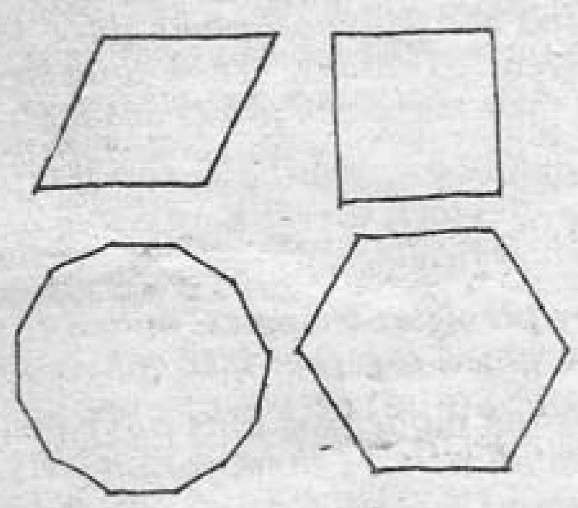
*So "Cast your bread upon the waters..."* Ecclesiastes 11: 1. *We're on for a long ride.*

ROBERT C. VEIT Jr.
GROSSE POINTE FARMS, MICH.

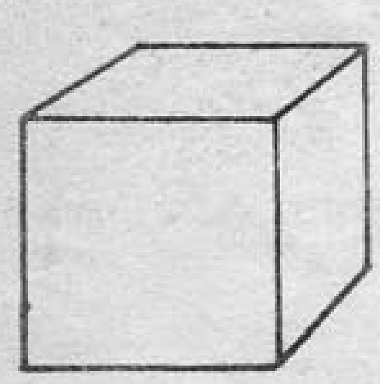
# ZOMES

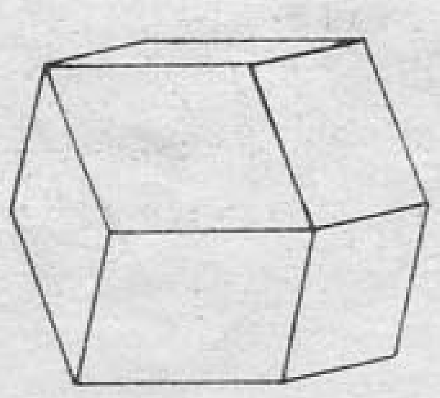

Garnet crystal zome at Placitas, New Mexico

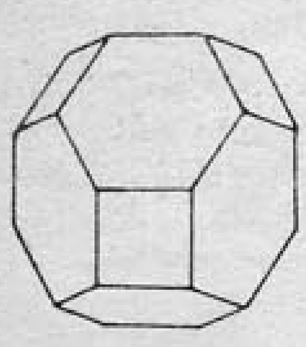
Steve Baer has developed structures from a class of polyhedra he calls *zonohedra.* "A zonohedron is a convex solid all of whose faces are polygons with edges in equal and parallel pairs." The possible faces look like this:

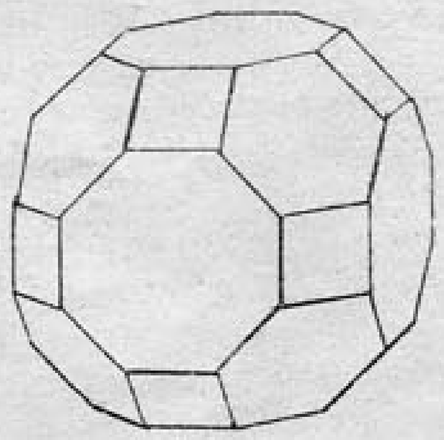


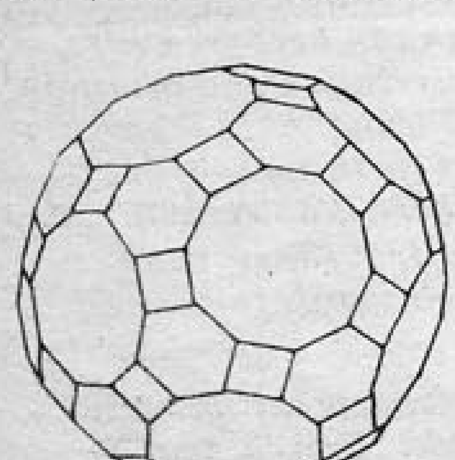
Some zonohedra:

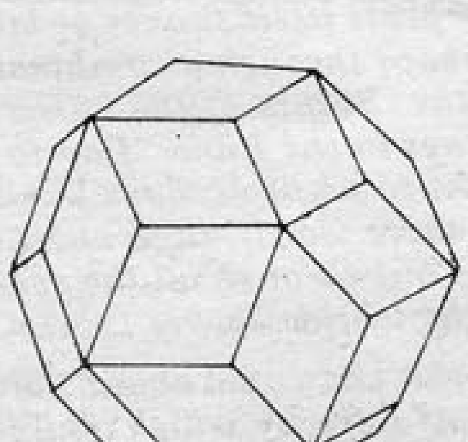

CUBE

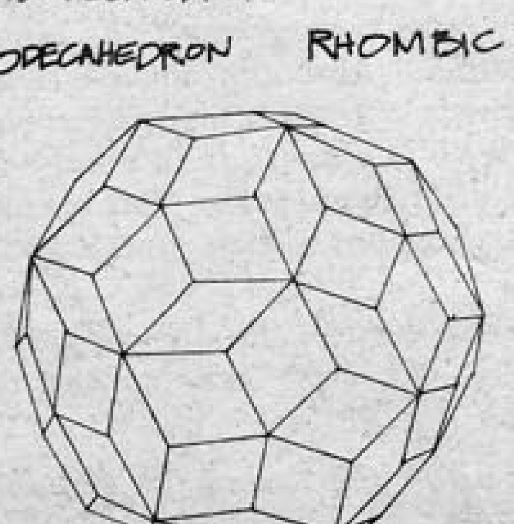

RHOMBIC DODECAHEDRON


TRUNCATED OCTAHEDRON

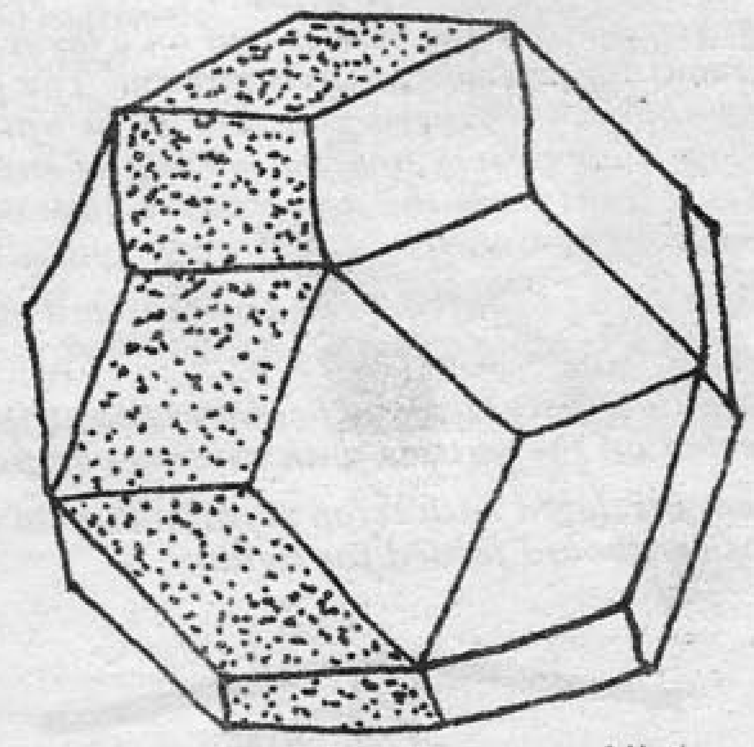

TRUNCATED CUBOCTAHEDRON


GREAT RHOMBICOSIDODECAHEDRON OR TRUNCATED ICOSIDODECAHEDRON


RHOMBIC TRIACONTAHEDRON


RHOMBIC ENENICONTAHEDRON

The unique thing about these polyhedra is that they can be stretched along a zone. "A zone of edges is a band of parallel edges which circles the solid."



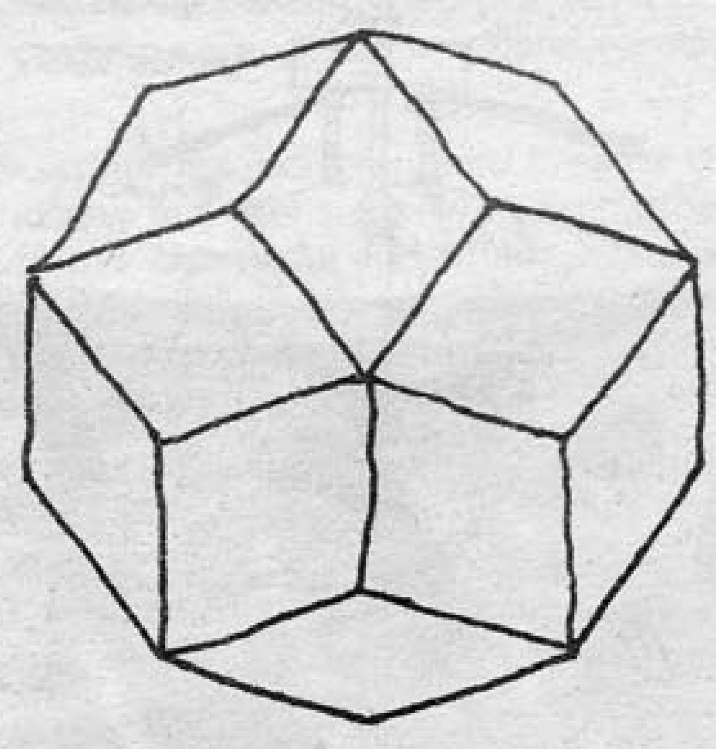
All the parallel edges in the zone can be lengthened (the structure becoming larger and more asymmetrical) without changing any other part of the polyhedron or distorting any of the angles. More than one zone can be stretched in the same polyhedron to produce many interesting and varied shapes. The zonohedra also have the valuable property of being able to nest without any special truncations.

There is a cut out model of the Rhombic Triacontahedron on p. 126. The following instructions for the construction of a 25' triacontahedron were written by Barry Hickman, who has been working with Zomeworks for several years.

*The triacontahedron is a semi-regular figure made of one diamond with face angles of 63° 26' 06" and 116° 33' 54" and one dihedral angle of 144° between the diamonds.*

*When it is used as a dome and all the edges are equal, the floor is circular. It can also be made with an oval floor, by stretching sets of parallel edges (when a set of parallel edges is "stretched" the figure is called a Zome).*

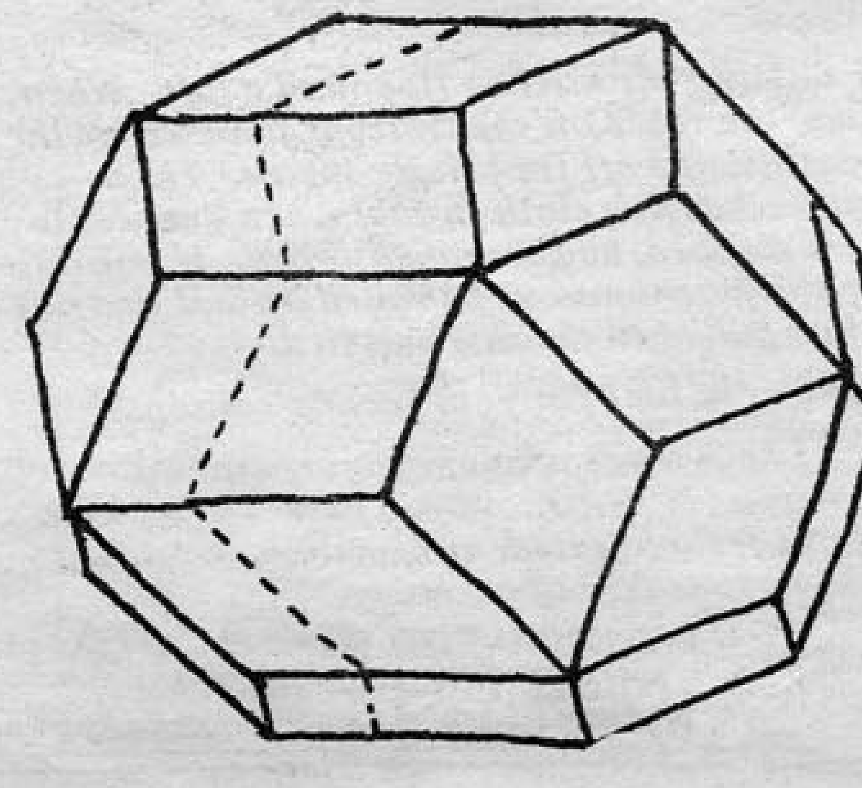
*To make an oval shape, it is easiest to first make a circular one and then add the desired lengths. If we make a pentagonal vertex the top, then from the top a circular floor would look like:*

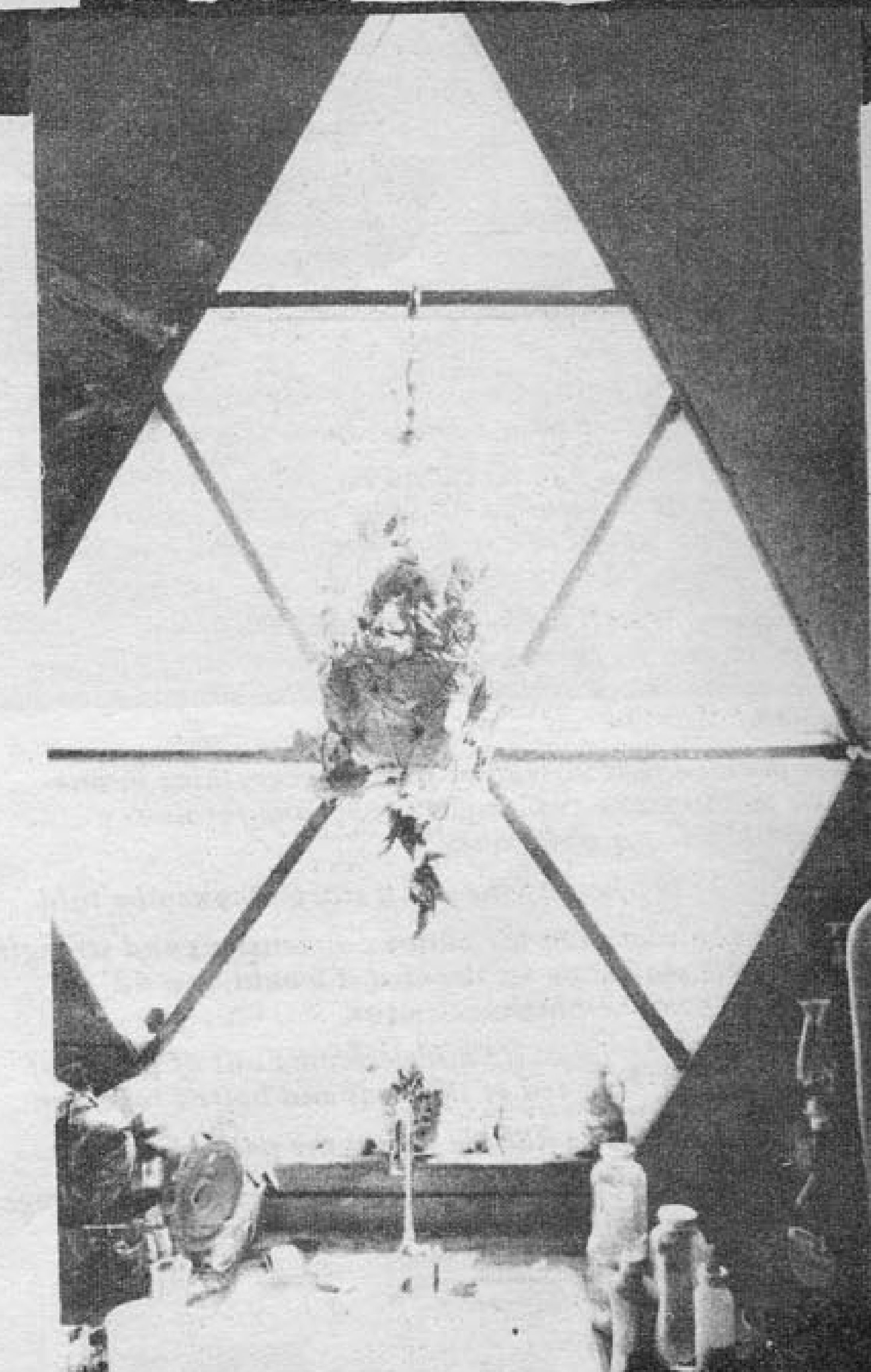


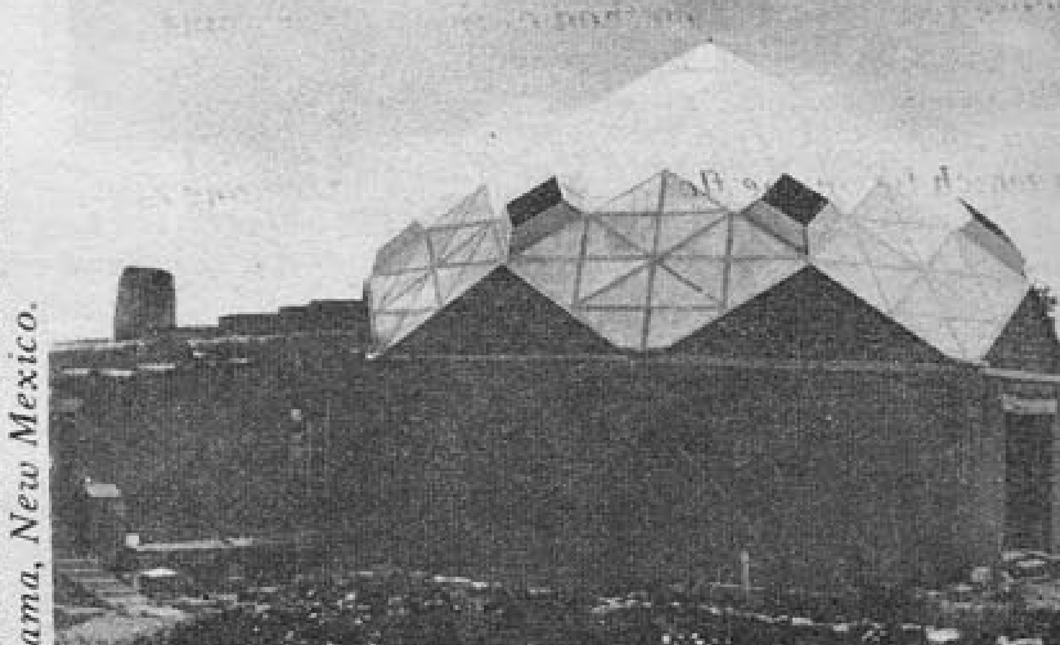
*The walls are vertical, so they can't be seen in this view.*

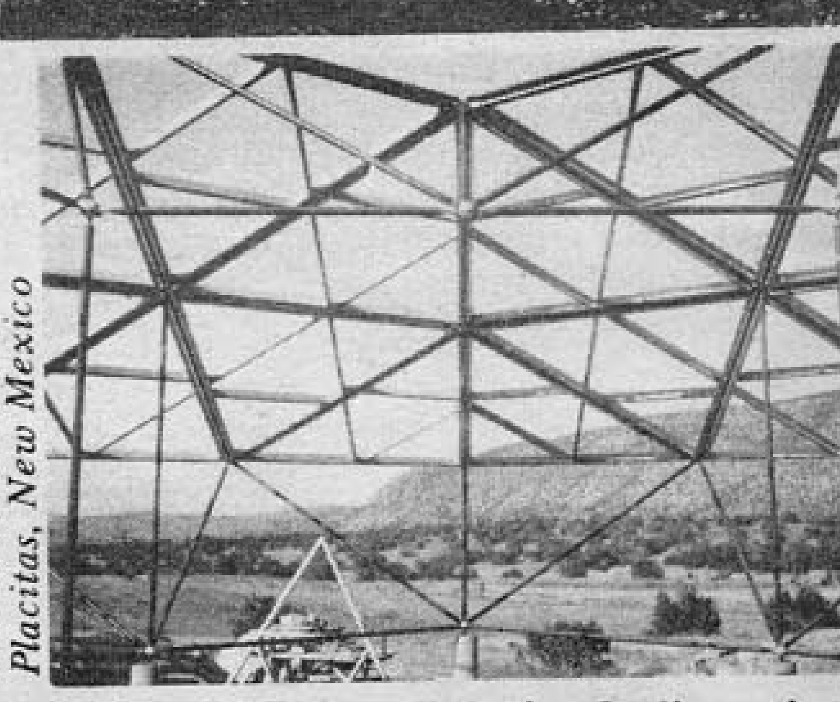
*If an edge length (e) is 8.9427', then the diameter is 25.89', If you wish to make one a different size, set up the ratio 8.9427/25.89 = new edge length/new diameter (chord factor .3575).*

*In order to make the floor oval, we stretch parallel lines*



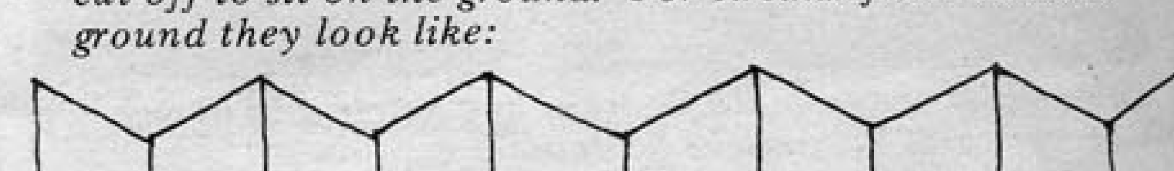



46' enenacontrahedron zome at Lama, New Mexico.


Bo Ford's zome at Placitas, New Mexico

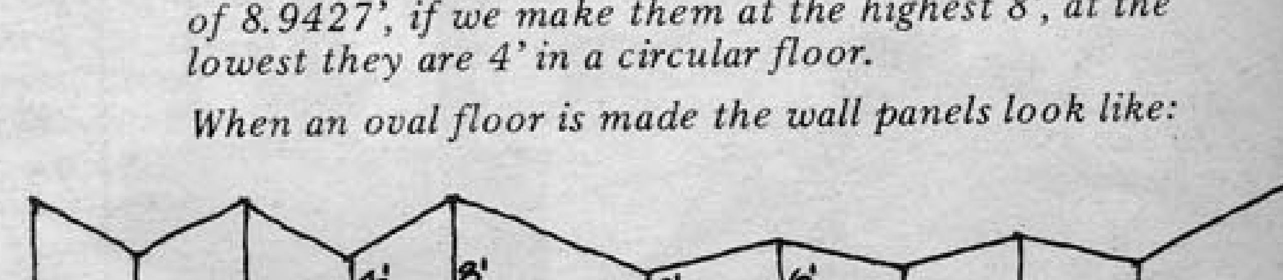
*The added length (e') is 4.4720'. The "stretched" lengths are e+e' or 13.4147'. The narrow diameter is still 25.89' and the new long diameter is 29.89'. The floor area has increased from 492.429 sq ft to 590.912 sq ft.*

*The vertical or wall panels are the regular diamonds cut-off to sit on the ground. For circular floor on level ground they look like:*



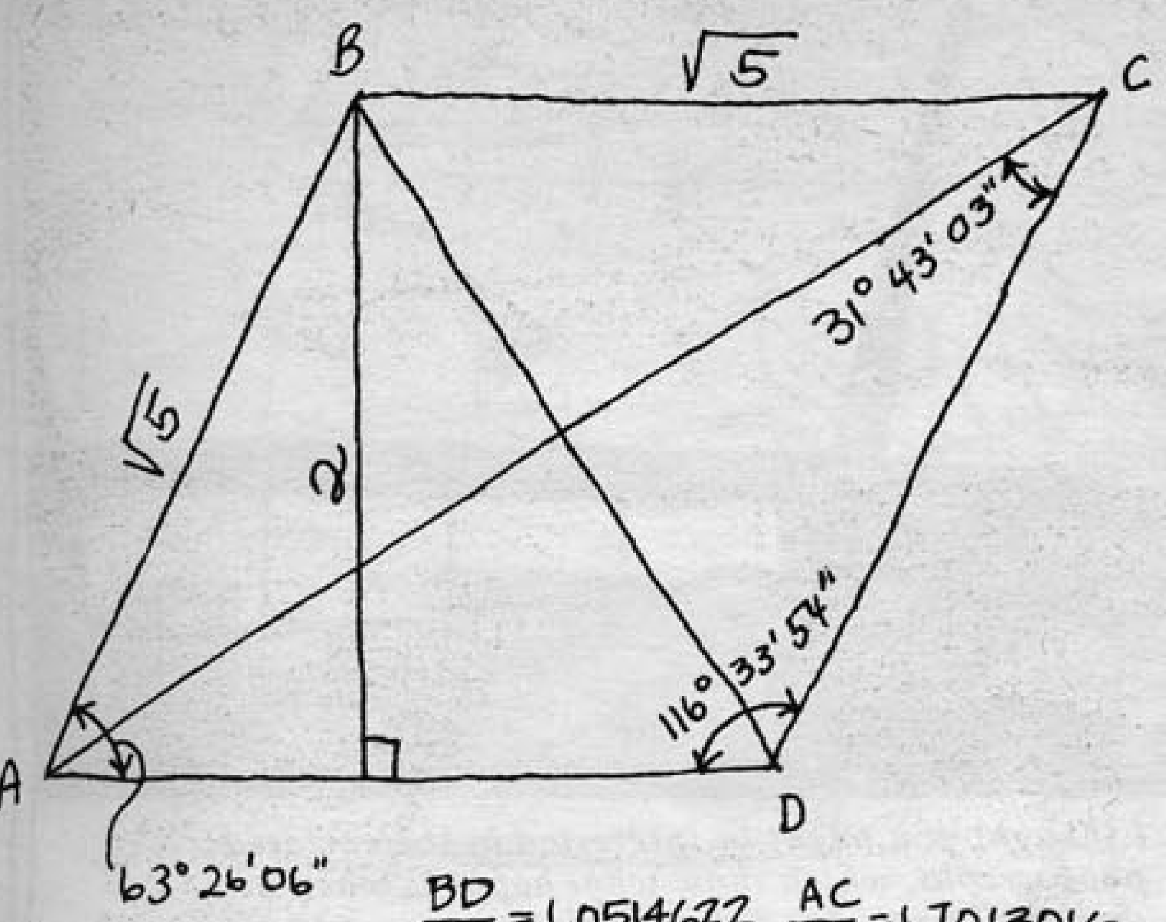
*There are 10 of them, 5 right and 5 left handed. Their height depends on how high you want them. The slope of the upper edges is 2:1, so with an edge of 8.9427', if we make them at the highest 8', at the lowest they are 4' in a circular floor.*

*When an oval floor is made the wall panels look like:*




*Again, 10 panels, but now there are 3 sets of right and left handed. The slope is still 2:l. The high point on the stretched panels is 8' and the low is 2'. The low on the short is 2' and high is 6'.*

*Critical constants of the diamond are:*




$$\frac{BD}{AB} = 1.0514622 \quad \frac{AC}{AB} = 1.7013016$$

$$\frac{BD}{RADIUS} = \frac{9.4029}{12.945} \approx .363$$

$$\frac{AB}{RADIUS} = \frac{8.9427}{12.945} \approx .3575$$

*Using these relationships:*

*edge 8.9427*
*diagonal 9.4029*
*long edge 13.4147*
*long diag. 12.3559*
*wall heights 8, 6, 4 and 2*

*Now is a good time to make a model. Stiff paper or lightweight cardboard is good. Cut the diamonds and tape them together. Once the model is made, it is easy to count the necessary pieces. The top panels take:*

| | |
|---|---|
| *20 edges* | *5 long edges* |
| *6 diagonals* | *4 long diagonals* |

*This count includes the top edges for the vertical panels. The vertical edges take:*

| | |
|---|---|
| *3-8'* | *2-4'* |
| *2-6'* | *3-2' plus the pieces along the floor, which* |

*take 8-8' and 2-12'.*

*The diagonals for the vertical panels are the same as the diagonals for the equivalent roof panels, except for the short panels, which have a diagonal of 8.246'.*

*If you use the structural method of the Big Sur dome, you'll see that you need twice as many pieces of wood than the count shows. Ripping a 4 X 4 will give you those. You don't have to rip the wood for the diagonals or the pieces which lie on the floor. So for each edge, long edge, vertical edge count one 4 X 4 each. When you look at the diamond, you'll see that there are an equal number of right and left handed ones. This means that you'll need 20 right handed edges and 20 left handed edges, etc.*

*To use the Big Sur dome method, merely change the dihedral angle to 144 and the tip angles to 63°26' and 116°34'. These are the full angle, you want to cut the wood so the angle on the tip is one-half of those angles.*

*Using an approximately 8' edge, you should use 5 3/8" bolts per side. Erection is a little easier with the extra bracing, so put a gusset plate on both sides of each corner. Where a diagonal comes in, make the plate big enough to put a couple of nails in the diagonals. It is also a good idea to put some 16d finish nails through the tips, and where the diagonals are, into them.*

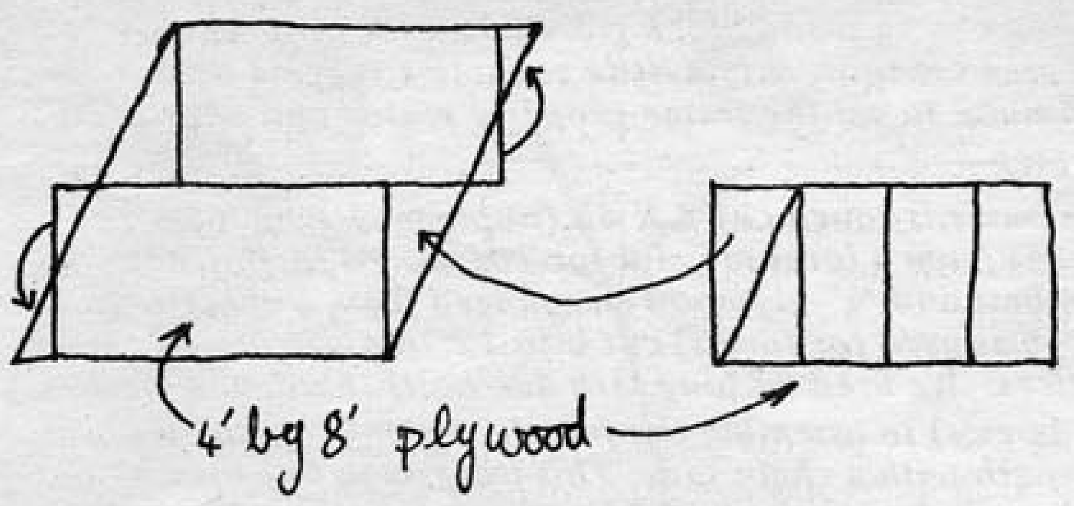
*When cutting the vertical edges, remember that they hit the pieces that lie on the floor at 90°. You can cut the pieces that lie on the floor to rest under the vertical edges, in which case you'll cut the vertical edges shorter by the width of the material you use for the floor pieces. 2 X 4"s work fine for the floor pieces.*

*It is almost indispensable to make a jig for the diamonds. It can be simple, several of the pieces of plywood screwed together, with an exact drawing of the diamond on it. Put some blocks so the edges when placed inside they will come right up to the line.*

*Place the edges in the jig, the big side down. The outside edge should lie on the line. If there is a gap at the tips, put a shim in it. Place the 4 X 4 you're going to use for the diagonal where it belongs and mark it, cut it, put it back in, if it's too short, shim it. Nail the corners with the 16d nails and put the gussets on. Be careful when you go to turn it over, it'll be a little loose. Place the gussets on the other side. It's ready to drill.*

*It's good to build a jig for drilling. Not much, a 2 X 4 with holes in it at the right distances and size. Try to keep the end holes close to the corner, but leave enough room to get the bolt in. Remember that the obtuse angles always go together, so holes have to always be the same distance from the corner. You can clamp the jig on the diamond with vise-grips. The hole has to be perpendicular to the bevelled edge.*

*The particular diamond we're working with has a height of 8'. This means that you can cover it with exactly 2¼ sheets of plywood with no waste.*




*You'll need more bracing, unless you use very heavy plywood.*

*for further information on Zomes see* Dome Cookbook *$1—Cookbook Fund, Lama Foundation, PO Box 422, Carrales New Mexico 87048, and,*

*the more technical* Zome Primer *$3—available from Zomeworks.*

*We are producing panels for triacontahedra and other more complicated Zomes. Write for further details*

*Steve Baer*
*Zomeworks Corporation*
*PO Box 712, Albuquerque*
*New Mexico 87103.*

**44' one-frequency icosa**

*Thanks for the mail relating to* Domebook Two. *Good aspiration.*

*My dome project grew from the incredible architectural poverty associated with money grab day care centers (less imagination than a functional chicken coop).*

*Betty and I bought acreage that is wooded and secluded within one mile of this city (Hamilton, Ohio).*

*(Our) Early planning borrowed from Wright's berm construction as an answer to economy in heating and cooling. The land seemed suited for berm with a hearty southeast downward slope and deep rills.*

*We decided early to pick our own rocks, wreck our own old buildings, buy bargains as they develop (such as reinforcing rods left over from big projects). We saw indebtedness as ruination so we saved until we could afford an item. The great workhorse is an old 4 wheel drive International panel that won't wear out, and a small John Deere with a 3 point hitch scoop.*

*Two years ago we decided on a dome. The local Universities were no help whatsoever. Raleigh procrastinated twice. Bucky wasn't home but his office furnished a paper on chords.*

*Our dome is similar to a melon on a pedestal within a salad bowl where the sphere is concentric to it's "void" (shell surrounding it to half it's height). The bowl is fieldstone. A pond at the bottom provides moisture to the planters in the wall. The outer shell of the bowl is 66' in diameter. The dome itself is 44' in diameter. As a 1-frequency icosahedron with equal members of 22' (plus joint) I cannot get a commitment about the 30 to 1 ratio rule for member lengths to width ratio. Does anyone know if I need a 10" diameter pipe member and if so—what wall thickness?*

*The bowl is set into a ridge (17' deep excavation). In spite of the depth the lowest point in the excavation is well above the two rills on both sides of the ridge.*

*A dodecahedron inside the outer frame will provide the weather barrier. Each pentagon will be on subassemblies similar to the Ford Rotunda dome at Dearborn. Main member pipes on the outside will be wrapped with copper.*

*Subpods inside the dome will be suspended from shanks growing up from the core and will be independent from the the dome's members.*

*We will experiment with light control systems, with mirror reflecting panels, with year around greenery beneath the "floors", with human excrement recycling without a water carry system, and with joint design.*

*There may be some "berm" benefits from the placement of the structure into earth. It will be truly fireproof—the gas boiler buried in a vault with a blast area "out of reach". And the icosahedron will rest on an edge (as opposed to a point or a face) to provide the desired aesthetics and dodecahedron "roof" development (slope).*

*A driveway of paving brick is 1/3 finished. Tree work was done, water was rechanneled (polluted from above), underground wiring is nearly finished and a rural water system will be operational by the driveway in two months. Our taxes are much less than owning a road frontage property. We get fresh air due to the westside location, and we have no neighbors in 190° from the site.*

*Wright's "democracy in overalls" thing feels good. Thanks for your help.*

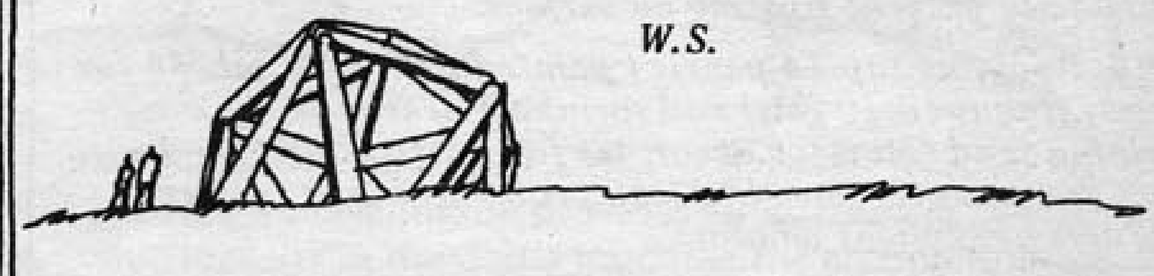
*Wendell Spencer*
*Hamilton, Ohio*

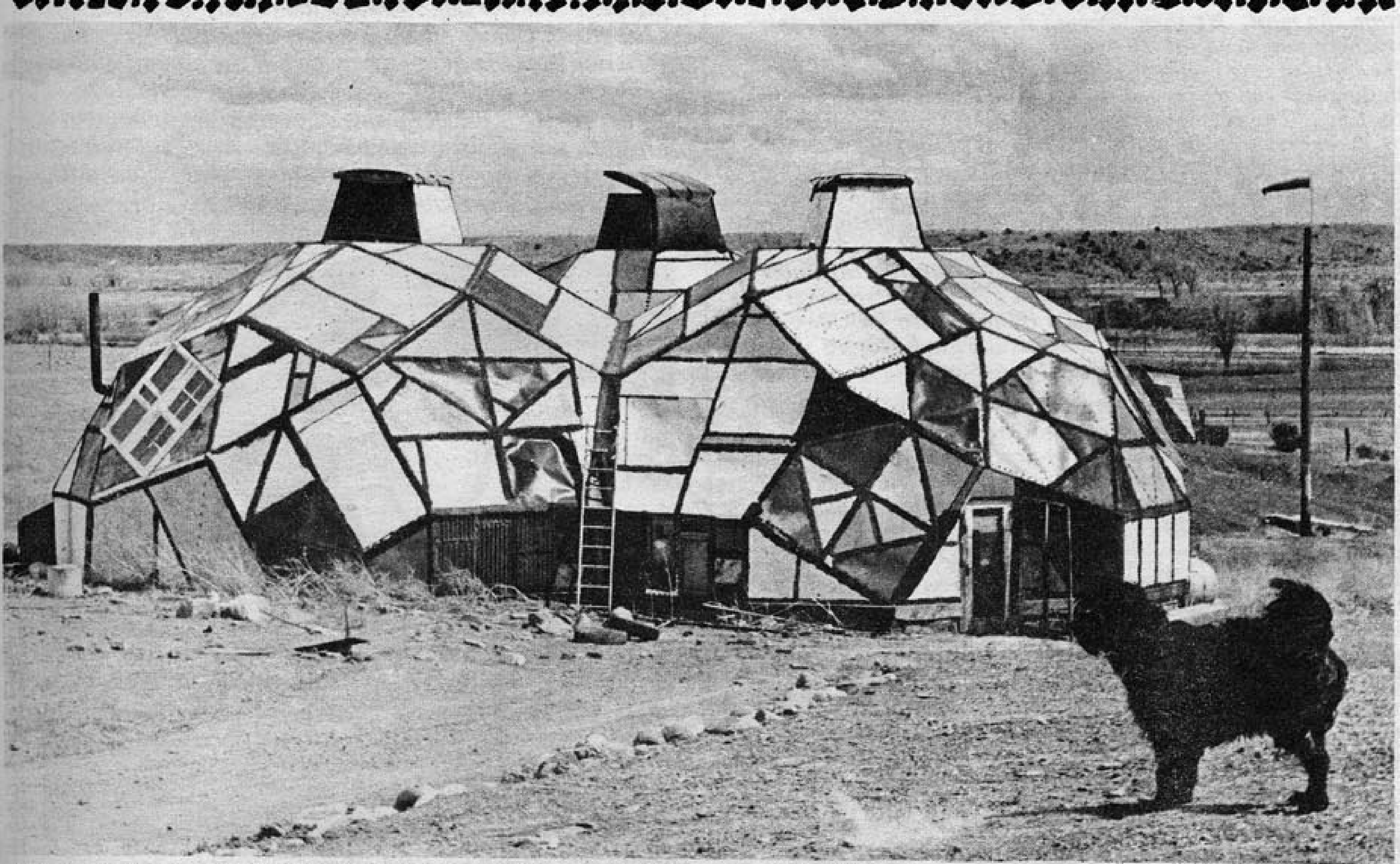
*See Popko's* Geodesics, *figure No. 2, lower left, for basic configuration of our dome.*

*Betty insists that I add a note.*

*I have mentally moved into the structure, walked about in it, and looked out of it. Therefore part of the letter indicates the building may be finished. No. I am gathering reinforcing rods now for the rather massive footer for the retaining wall (bowl). With some luck with the weather, that component should be finished in January.*

*W.S.*





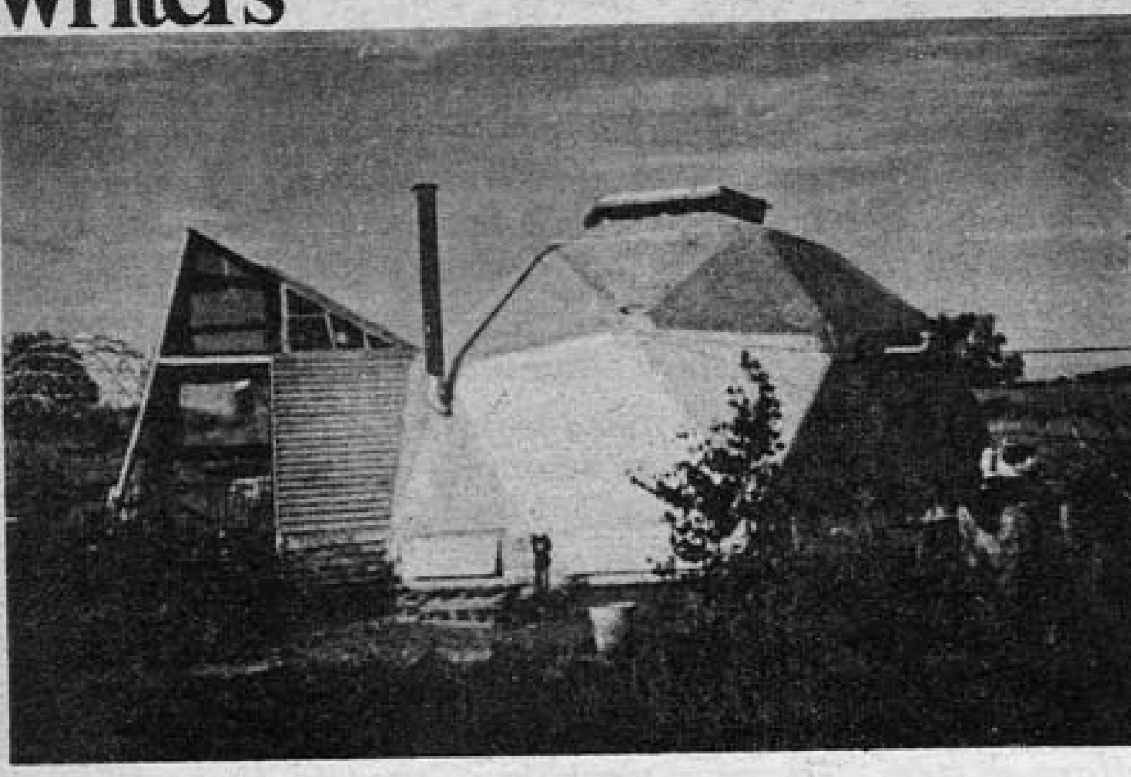
*A big mirror hung over the chest of drawers, adding size to the room, and a high ceiling, a rug on the floor. The bed was a big piece of plywood, supported by cinder blacks, raised eight inches off the floor to keep us from having to share the bed with an occasional centipede. Scorpions, centipedes and spiders lived around us, with us and no one ever got bitten. After a while they become accepted as part of the scenery, part of the balance in the natural surroundings. I was raised in the swamp country of North Carolina and had little trouble with the creepy, crawly things, but some of the city people, especially people from New York, wd really freak out when they began to see the type of life that teemed in the desert. They, however, didn't mind cockroaches or rats and I shudder at the sight of either. On the plywood we had a double mattress covered with cool green sheets and pillowcases and a verdant green bedspread my mother had given us, all green, the color of healing, an easy color to live with, especially in the New Mexico mountains with a different pallet working, of earth colors, ochres, siennas and different shades of green than the green lawns and trees of Lawrence, Kansas that Jane came from.*

*From a book in progress*
*by Steve Katona*

*At left: Baer's fused triple rhombicosadodecahedra at Drop City, Colorado*

*Below: Bill Chaitkin made this model from the* Dome Cookbook *of two fused rhombicosadodecahedra.*

# writers



**American "Domes"**

*Gentlemen:*

*I acquired a copy of your first issue of* Domebook One *and I applaude your interprise. I found your book interesting in certain respects: good format, good layout, etc.*

*Since you ask for "...criticism" I take the liberty to suggest you add to the next issue: first a concise but good history of polyhedra including, of course, the origins of the 5 regulars, the 13 semiregulars, the 13 duals (mine), the stellated polyhedra, the truncated, the interpenetrated et cetera. All these classes of polyhedra are the most important because, as you know, they represent the prototypes of our modern structures called by the Americans "Domes". The article in history of polyhedra should have been done in the very beginning of your publication but it is better late than never.*

*Secondly, the drawings are full of mistakes of perspective. You need to improve how to draw free hand and to draft. The two ways of drawing have to be coherents as much as possible in order to avoid conflict of styles.*

*I am also including here one book regarding my discoveries of the 13 duals of the Archimedean polyhedra. This book teaches how to obtain one kind of polyhedron from two other different interpenetrated polyhedra. My book contains 13 geometric discoveries and 10 new forms of polyhedra.*

*In your next page devoted to the Bibliography you can include also besides my book, the excellent book of Dr. Burt. Burt, M.* Spacial Arrangement and Polyhedra with Curved Surfaces and their Architectural Applications. *Israel Institute of Technology. Haifa, 1966.*

*I am sure that there are many more deserving publications to be included in your Bibliography, especially those published over seas of which you should be aware.*

*Hoping to hear from you soon, I remain, sincerely yours,*

*Adriano Graziotti*
*Seattle, Washington*

**Alaska**

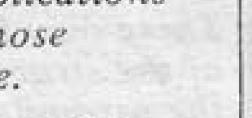
*Friends,*

*Have been meaning to write since I visited the fellow who runs Dyna-Dome in Phoenix, can't remember his name. He gave me your address which I lost but just picked up again from Mother Earth News.*

*With the connectors I bought from Dyna-Dome I went to Alaska last summer, along with 400 lbs (3, 14' X 25' pieces) of mill felt, a heavy duty weave of fiberglass and cotton canvas, available in approx. 14' X 25' sheets for $8 from the Port Angeles, Wash. area (paper mill comp.).*

*Using 6 mill Vis-queen (trade name plastic) cut in triangles as a vapor barrier on the inside of the 26' dome 2 X 4 frame. Then putting 3-5/8" fiberglass insulation in all triangular panels (fiberglass cost $120) and finally covering the panels on the outside with the mill felt each panel cut individually (cutting from 14' X 25' rectangular leaves considerable extra, small pieces but it has many uses and it's cheap). Canvas all stapeled with 9/16" stapels. Two top panels were covered with plexi-glass as skylight on inside and outside to prevent frosting on surface.*

*The remaining top 14 panels I painted with road tar, $6 for 5 gals (required 10 gals) and sprinkled nearby free colored sand (sand for decor, tar for waterproofing). To this day however have had leak problems around lower corners of skylight window.*

*Constructed a 16' X 16' loft, framed by 5 16' spruce poles, which is totaly suspended by manilla ¼" rope at 4 points and chain in the center, no loft-to-floor supports.* 

*The 3 horizontal lines are spruce poles (the perspective is incorrect, the two upper ones shouldn't be visible in this view). It takes 8 sheets of plywood to cover loft and make floor. To keep plywood from bending spanning 7½' without support, have done the following:* 



*The holes are sufficient for ¼" manilla to pass thru two lengths of 7'; spruce poles are then tightly tied up against underside of board.*

*The heating is from wood stove in center of floor. A well was dug before anything else and there is a hand pump near the wall. Has been very comfortable only problem has been those leaks.*

*Total cost $450 (many things were scrounged and salvaged) total man hours approx. 150.*

*Hope some of this information is useful. Am traveling back to Alaska soon.*

*Peace, Jon Sobel*
*Wasilla, Alaska*

**Videofreex**

*I hope this is not too late to influence* Domebook Two*— our commune started building a dome this summer which is still not complete but we have learned a few valuable lessons which I would like to pass on—we are located in northern Vermont on a 130 acre piece of mostly wooded land. When we came on the land, there were no buildings and it was June. We had never designed and built anything before as individuals and were a new commune. We started a 32' 4-frequency (alternate) hemisphere in June. We laid out the foundation to include 20 small footings each going to a depth 4' (a lot of frost in Vermont) and rising to a common elevation. We used a central post set at this elevation and line level to set the forms at the proper elevation. The footings were at least 1½' above ground level to protect against rot and termites.*

*We mixed the concrete in a gasoline powered mixer: 1 part cement: 2½ parts sand: 5 parts crusher stone using just enough water to make it workable but not soupy. The concrete was poured 1 or 1½ ft at a time and then rodded with a wooden rod to remove air bubbles and compact the concrete.*

*Curing was done by covering the tops of the forms with polyethelene for about 8 days before stripping the forms. The footings each had a short piece of 2 X 4 bolted to the top and on top of this block and was spiked into it. The foundation was completed after the frame was finished by filling the space between footings with a field stone knee wall. The mortar for setting the stones was mixed: 1 part cement: 1 part lime: about 6 parts sand. Doing field stone walls is easy and works really well if you place the stones so that they support themselves. The mortar should give little or no support. Old stone walls are a fine source of stone. All the wood that contacts the masonry should be creasoted to prevent rot.*

*I think that this foundation is pretty cheap (if field stone is easily available) and should work well in a heavy frost area. Time will tell. If the holes are carefully placed the frame will come out to lie pretty well on the footings. Nailing onto a wood block gives you a lot of flexibilty in this area. It took only a little collective tugging by our commune to get the frame properly seated and nailed (20 people).*

*The frame is rough cut 2 X 4's (unplaned), which we bought from a local sawmill for 10¢/board ft, for the members and ¾" plywood (scrounged from a construction site—was used for forms) cut into 12" dia. circles for vertices. We used 5" long, 3/8 dia. bolts (hardened steel cap screws) to assemble the frame. We cut the 2 X 4's to length with a chain saw. This was rough but the distance between the bolt holes was precisely measured—one hole in each end of the member—before the holes were drilled with an electric drill. We cut a 9° angle off the end of each member using a template to mark with and a table saw to cut with—by approximating the axial angle to 81° (hence the 9° cut) we were able to speed the cutting, we were careful cutting but not meticulous and I think all the angles were somewhere between 7° and 11°. We were meticulous about the distance between bolt holes in the members and the vertices. This method worked very well. The frame was assembled quickly with a reasonable amount of tugging and prying by a 5 person crew and 1 crow bar. We erected a mast in the center of the foundation with a pulley top and bottom and assembled the frame without using scaffolds or ladders by putting the top ring together first and hoisting it up the mast adding to the frame till the whole thing was hanging from the mast. We then lowered it onto the footings—this is where you need the 20 people—the dome hangs so that the bottom ring is elliptical in shape. By pushing and pulling it it can be forced to be round and set down on the footings. The plywood plates were bolted on the outside of the members. All work was done at ground level and the frame and foundation took a total of two weeks. The field stone took another week. The frame went together very well. After it was on the foundation the vertices were twisted around till things looked right and the bolts tightened. I forgot to mention another feature: the holes in the plywood hubs were drilled at 72° or 60° spacings and this worked out very well. I think that so far we were doing pretty well and that this is a good way to frame a dome.*

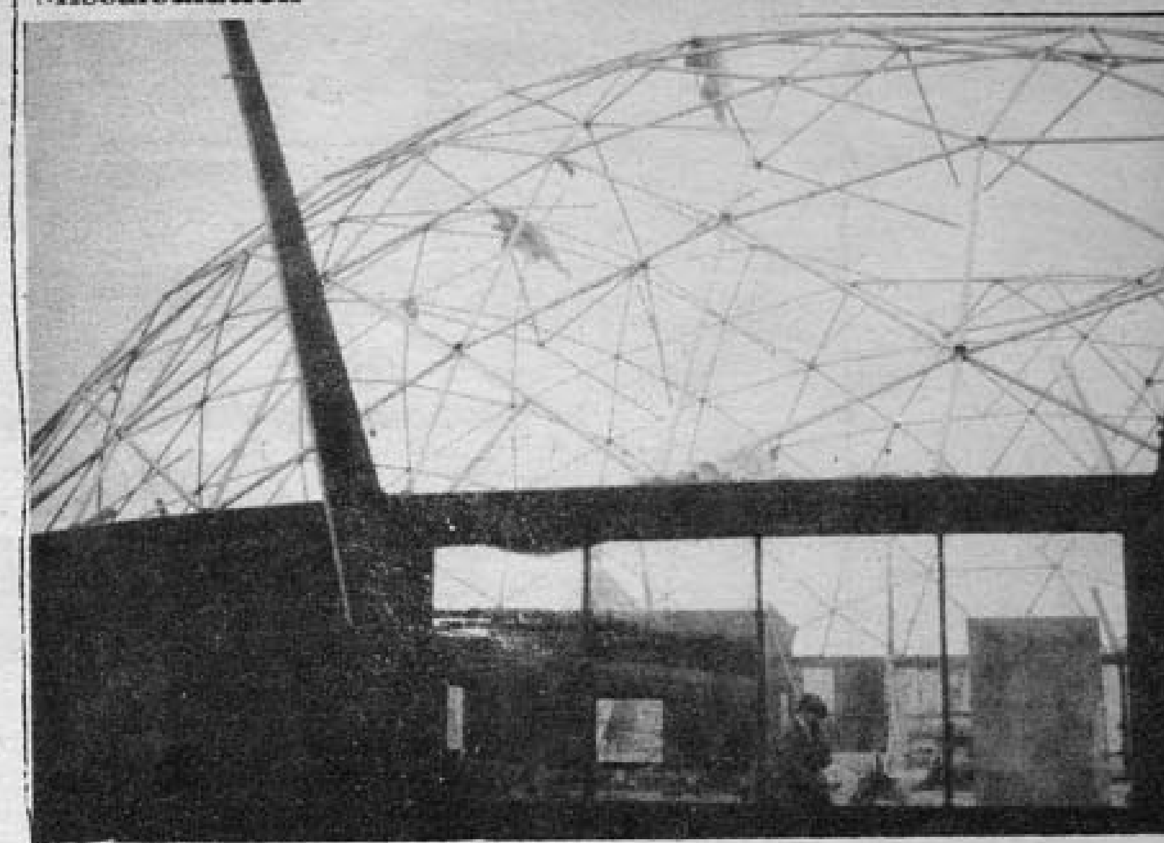
*We started covering it with panels cut from car tops. After trying several things we cut the car tops out with axes and then cut the panels out with oxy-acetylene torch. We then wire brushed and primed the burnt and scratched surfaces. Using No. 10 sheet metal screws to piece together panels when required, we then nailed up the panels (which were cut to overlap 2" and create a shingle effect) loosely, drilled for 2½" No. 10 round head wood screws, put down a bead of Thiokol caulk and screwed them down. The whole process was clumsy, slow, awkward, bitchy, often a drag to be doing and resulted in a mediocre weather seal. Wood screws just don't hold floppy, bendy car tops down tightly.*

*The video freex have a tape on ferrocement that's pretty good but it's based on experience in boat building.*

*Something on p. 3 of* Domebook One *about "Industrial Production of low cost housing" makes me feel weak and think of more suburban housing pollution and domes by the lake and in the woods and at the ski areas—wow, they're nicer than A-frames aren't they? Dear, yes dear they're so cute lets build one for a ski cottage—I hope that won't happen. I hope that the "craft and graft" industry will fade away never knowing about domes and that the newly emerging life style will emerge as a dropout from N.Y. City high rise extravaganza construction business. I really hope things won't fuck up again.*

*Love, Chico Drake*
*West Glover, Vermont*

**Miscalculation**



***I thought you might be interested in the enclosed photographs, which show what happens when a domebuilder makes a miscalculation.***

*The dome is on Puget Sound in Edmonds, Washington, just north of Seattle, which I personally viewed about two weeks ago while I was on the Coast. It is an aluminum dome built upon a 12' high wall about 70 or 80' in diam. I believe it might be a 3/8 sphere dome with 8 or 10 frequency. (Picture A) Beneath the frame of about 8' long aluminum cords, about .05" thick, 3¼" O.D., there was hanging a nylon canvas held by 10" diameter aluminum washers (Picture B).*

***Friends in Seattle told me that the dome was up for about** a year and a half before it collapsed. Picture C shows the type of hub unit used, made of cast aluminum.*

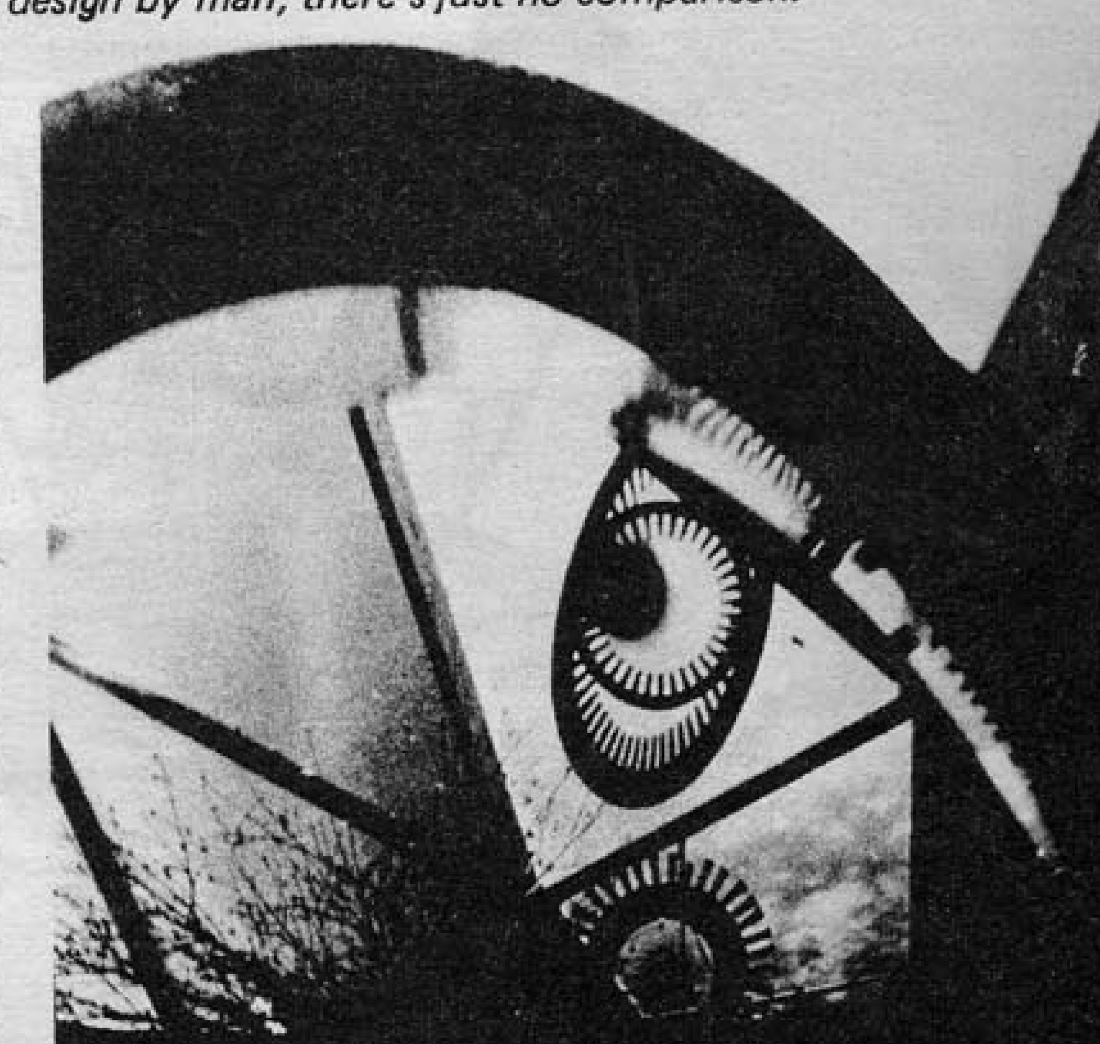
*I believe there were two possible reasons for the dome's collapse. One is that with its high frequency, it was so spherical that it lost the strength of the icosahedron. The other reason is that the aluminum hubs had insufficient tensile strength. Some of the hubs on the floor were bent inward.*

*I will forward to you a photo at the completion of our building our first dome.*

*Until then, best success.*

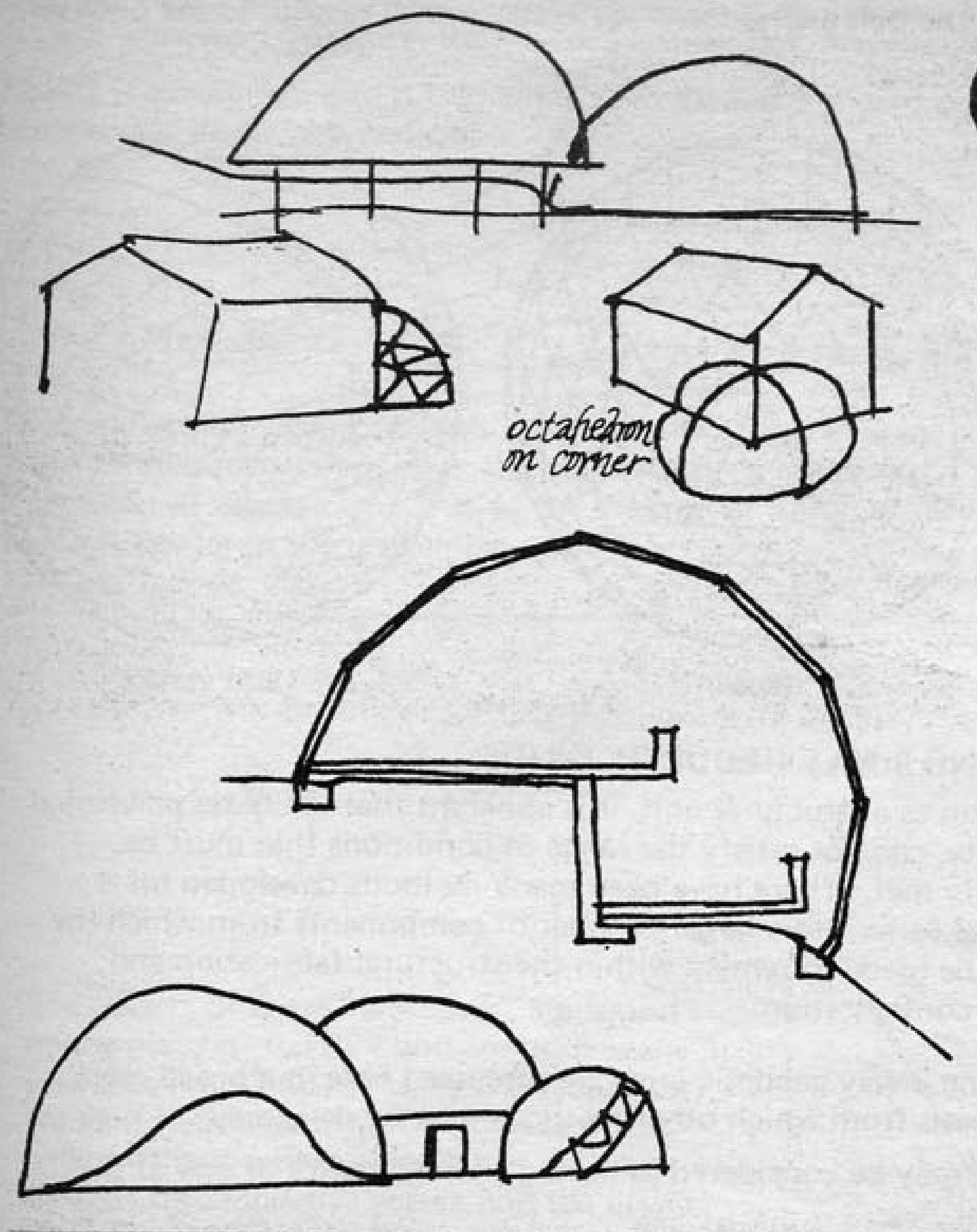
*Walter Wendel*
*Hicksville, New York*

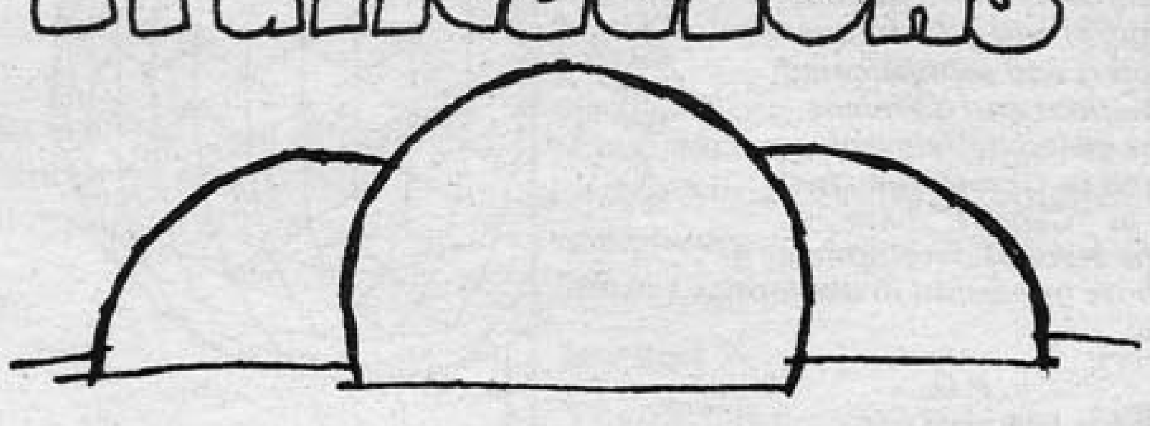
*Driving down Highway One Hans and I were eating apricots, talking about design, I was thinking about why things are the shape they are, because I'm thinking about what kind of shelter I want to build next. I looked at the apricot pit, it's for growing more apricot trees, it's made perfectly for that, it contains life inside that when in the ground springs up toward the warmth of the sun. Our homes should be that, designed for the life inside. Seems so presumptuous for man to talk about design by nature. When you consider the apricot pit, or winding stream, or retina as opposed to design by man, there's just no comparison.*

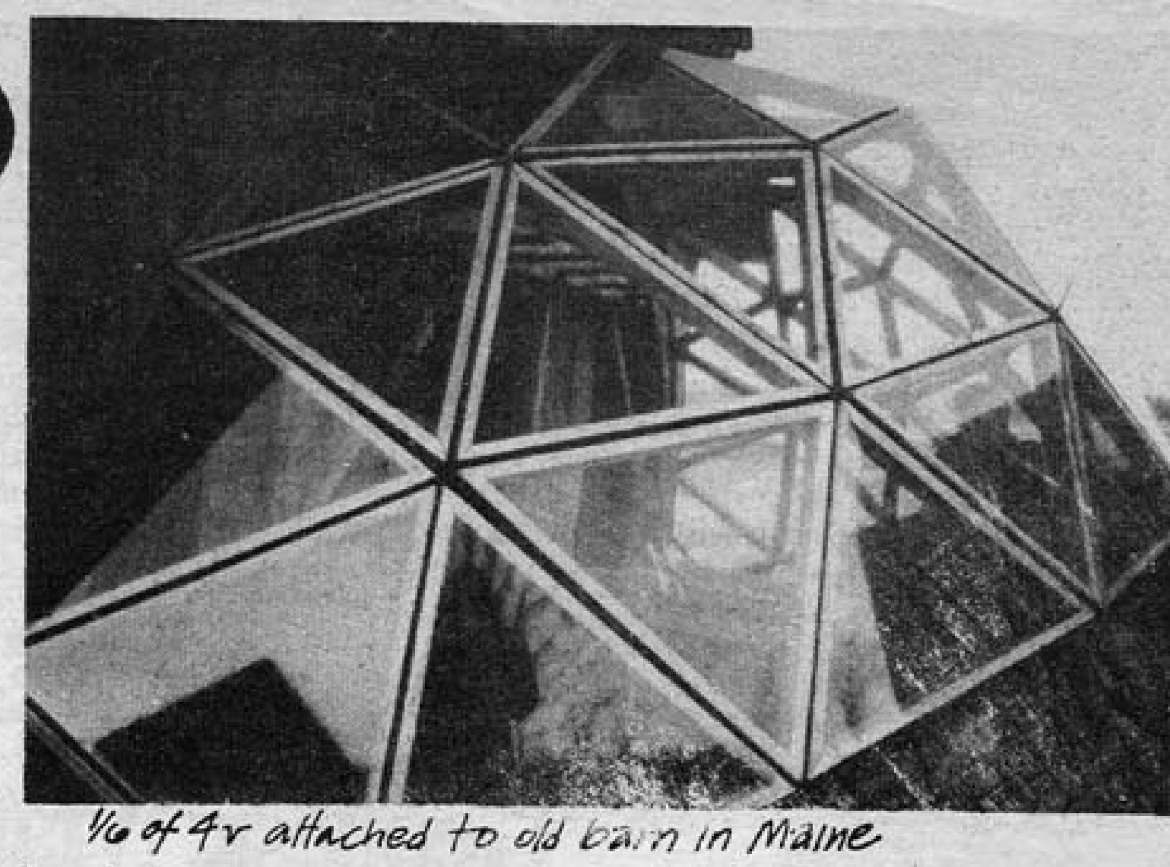


***Today I was visited by a girl who identified herself as the "Ice Cream Fairy", said she was working on a project for Carnation trying to talk them into establishing Merry Fairy Dairies—domes serving ice cream made from raw milk from cows eating organically. She wants to build the domes by heating sand and pouring hot hot glass over a mold. She expects to build the first one in Boulder Creek and digs domes, as she says they don't offer as much wind resistance as sharp-angled buildings, which slow down the earth's rotation.***

# CONNECTIONS
## and some
# Truncations



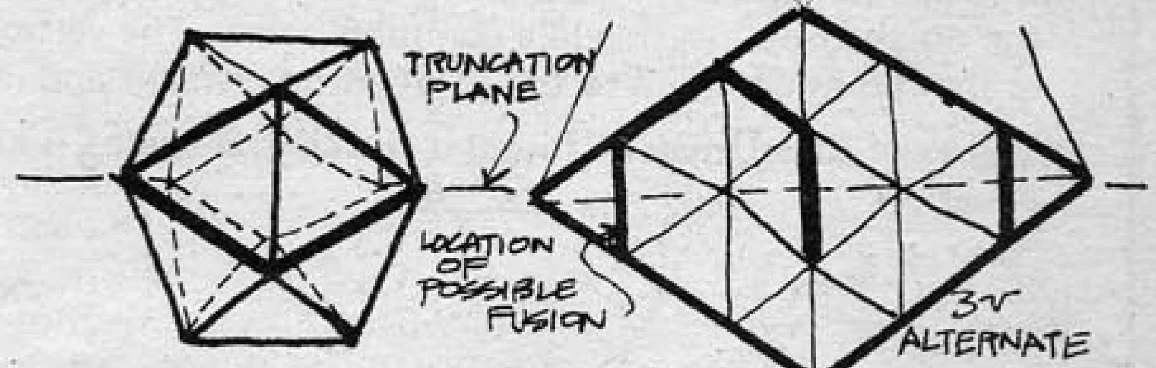


1/6 of 4v attached to old barn in Maine

Most of the truncations in the book are simple ground level cuts on an individual sphere. With the different orientations, vertex zenith, face zenith, and edge zenith, many interesting openings and/or enclosures are possible. Remember that all points of the dome do not have to touch the ground, and that any number of domes can be put together in any manner reasonable.

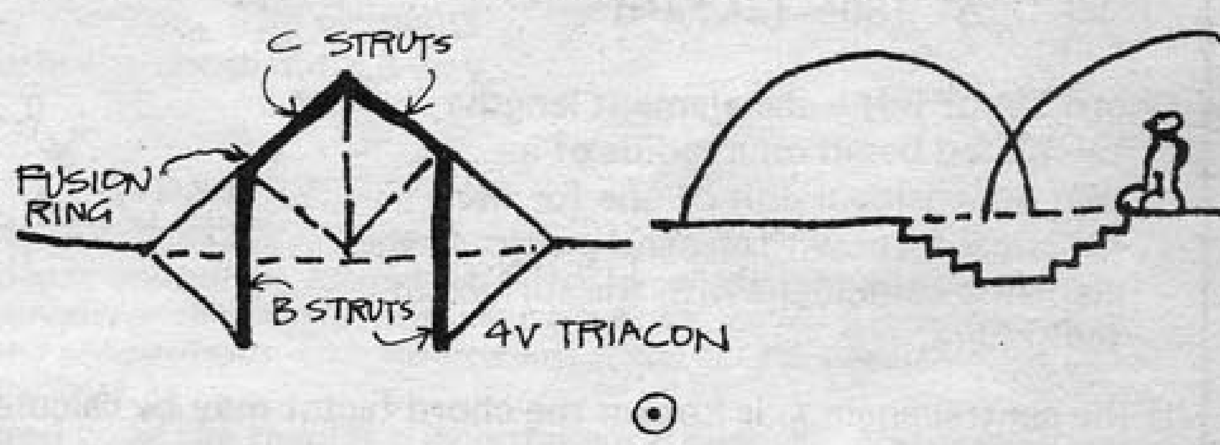
There are several ways to nest domes, by plane intersection (good for different sized domes or with different frequencies (v), by passages (works in almost any case and creates nice entrance hall), or by fusing (this means perfect coincidence of vertices and struts).

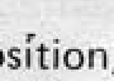
Another interesting orientation for the alternates is with the edge up. You need to cut the triangles of four of the principle icosa triangles, but it is a simple bisection of the B struts and the truncation results in a hemisphere for the 3v.



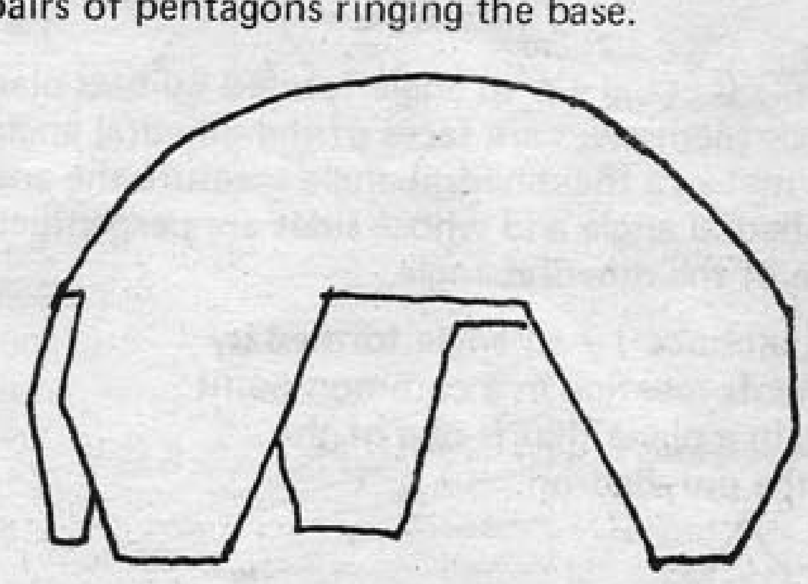

Since the bisected B struts are perpendicular to the ground, they will fuse perfectly with the same struts in another dome of equal size. This gives a way to nest hemispheres on the same level. The height of the fused section is not tall enough to walk through, so you would have to build a step down and then an up passage at the opening or bend over all the time.

The same type of fusion is possible with the 4v triacon in the edge up position. The bisected struts are once again perpendicular to the ground and will therefore fuse.

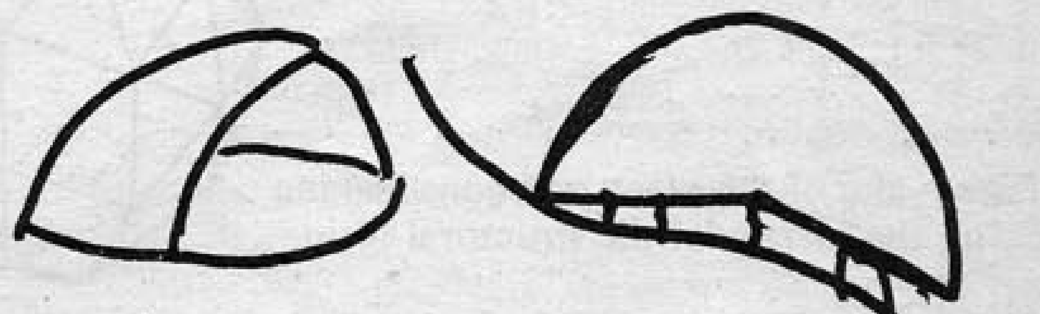


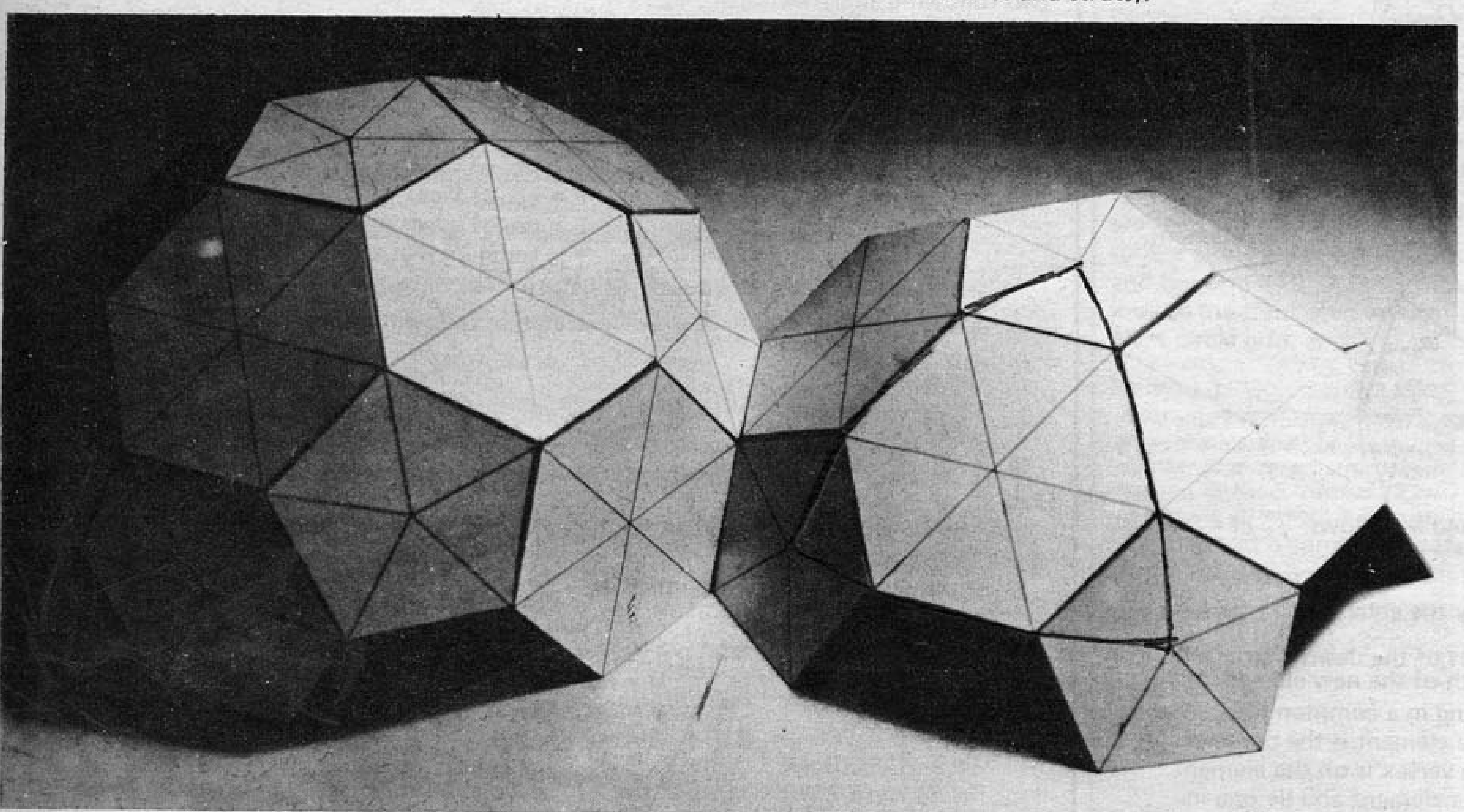



With the vertex up position, there are more truncation possibilities than the 3/8 and 5/8 on 3v. With a 5/8 on 3v, you could take out all the triangles between one or two of the pairs of pentagons ringing the base.



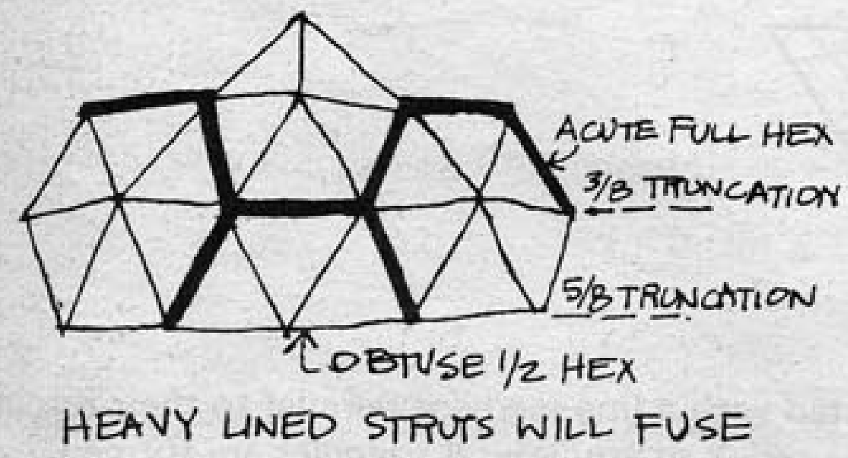
Or you can take an upward slice on one of the great circle arcs to give an even larger opening. You will probably need to support this arc with posts. The same thing can be done in a downward direction to enclose a lower level.



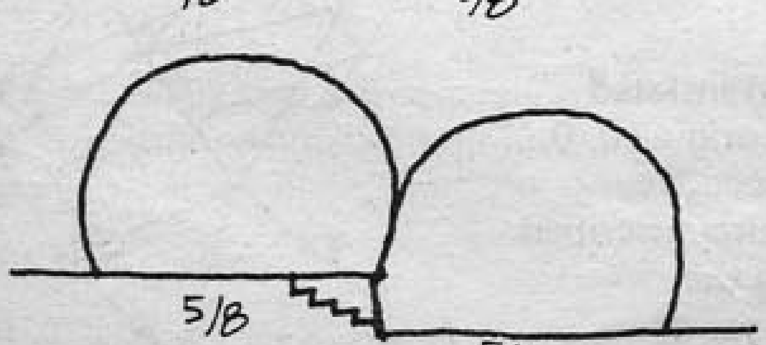


With the regular vertex up orientation, a very simple fusion is possible for two 5/8 3v of the same size. You can think of the 3v alternate as a truncated icosahedron made up of planar hexagons and pentagons because the two have the same vertices, except for the ones at the centers of the hexagons and pentagons (which are not projected out to the surface of a sphere in the truncated icosa). The angle between the half hexagon at the base (below one of the pentagons), and the ground is obtuse, and complementary with the acute angle between one of the full hexagons whose bottom is at the base (and between two pentagons) and the ground. The fact that they are complementary means that the angles add up to 180 degrees and will therefore fuse perfectly.

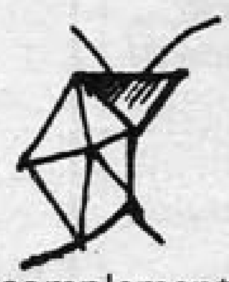
You can fuse the top of the full hexagon of one dome with the half hexagon of the other dome by building one of the 5/8 domes on a lower level, or by cutting one dome off at the 3/8 level.







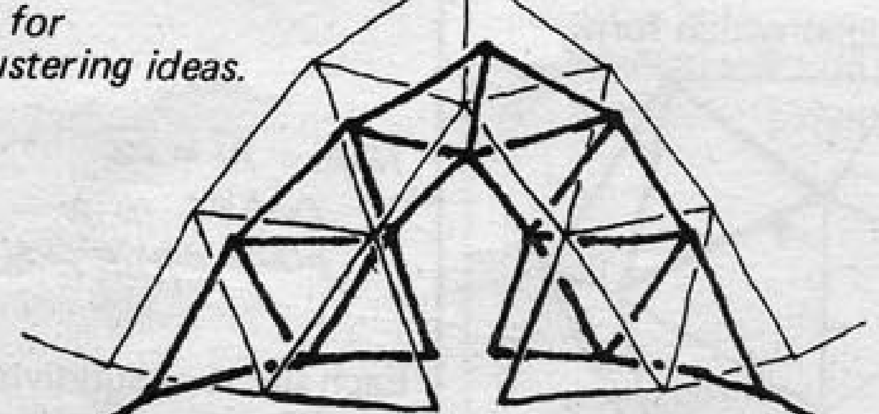

With the 3/8 connection, the opening wouldn't be tall enough so you would have to connect the triangles above the hexagons for enough head room:



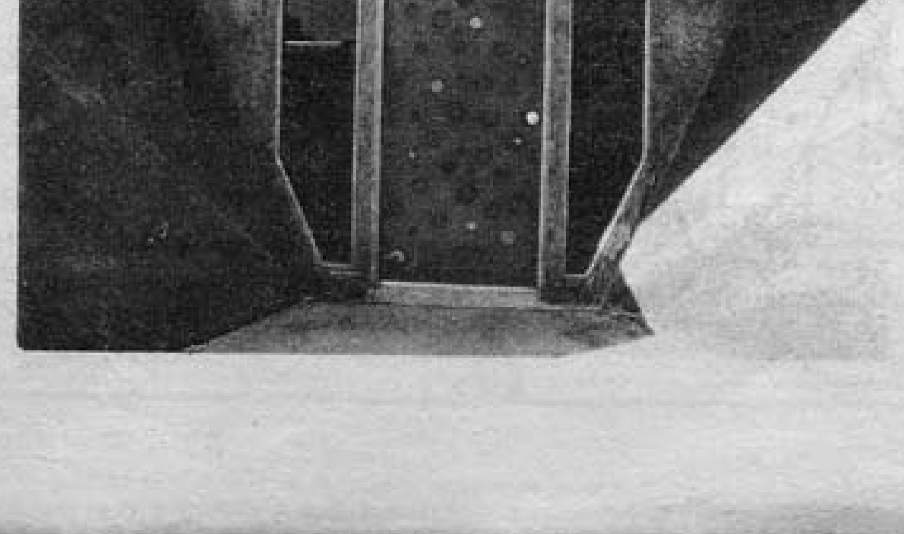
The plane icosahedron has complementary faces like the truncated icosahedron and will also fuse; the fusion ring will be a diamond.

Wayne worked out an intersection for 26-foot and 38-foot 5/8 domes. How the skin will intersect has not been worked out, probably just measure and cut special triangles after the frame is up and intersecting. They intersect with the pentagon vertex of the small dome just below the pentagon vertex of the large dome and the triangle below the pentagons spread to make a pentagon-shaped door.

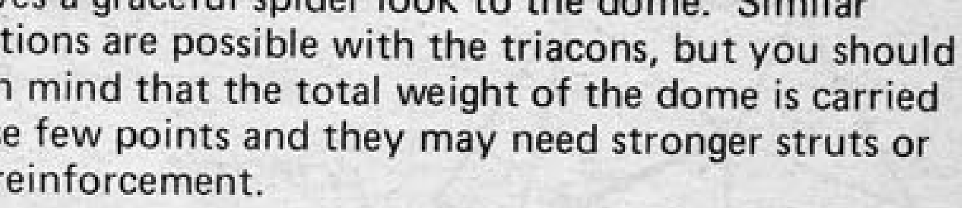
*See* Zome Primer *for truncation and clustering ideas.*



Many types of passages can be worked out to connect domes. For example, the full hexagons of the 3v with perpendiculars dropped from the 3/8 level could be connected to make a nice entrance, hallway or garden. Bill Woods of Dynadomes connects his octahedronal domes with passages like this.



The face-up orientation provides an interesting truncation which results in the dome touching the ground in three places and gives a graceful spider look to the dome. Similar truncations are possible with the triacons, but you should keep in mind that the total weight of the dome is carried in these few points and they may need stronger struts or other reinforcement.



There are endless possibilities for truncations and connections with other frequencies and type breakdowns. Making a stick model is the best way to check it out, just spend a long time looking at it from different angles. Keep in mind that to fuse domes you need two rings of struts which are complementary with respect to the ground (rectilinear structures fuse because all their faces are 90 degrees to the ground and therefore, always complementary), and to intersect or make a passageway, it's just a matter of playing it by ear.

Peter Calthorpe

*The following section is an article by Joe Clinton on the different methods of producing geodesics from the icosahedron. The technique he uses involves analytical geometry (Fuller used spherical trigonometry) and the calculations are done with a computer. The general procedure was to find the 3-dimensional coordinates of the vertices of the grid on the spherical surface, using the different methods, and then to calculate the chord lengths, angles etc. with these coordinates and analytical formulas. Joe worked with Fuller on his programs and was funded by NASA on a project called "Structural Design Concepts for Future Space Missions".*

*The specific motivation for developing these methods was to have a variety of forms to combine in large space frame domes. For example the Expo dome in Montreal is a combination of a 32-frequency regular triacon (Class II, method 3) and a 16-frequency truncatable alternate (Class I, method 3). With known parameters and sophisticated analysis, large structures can be optimized by different combinations and different methods; however, for small structures (up to 40') they are not generally relevant. What we generally call "alternate" breakdown in this book (and in* Domebook One) *Joe classifies as "Class I"; what we call "triacon", he classifies as "Class II". Joe wrote this section mainly with the intent of communicating the state of development of geodesic geometries and the hope that it would be an aid to those interested in exploring and expanding this field. Domebook comments are in italics.*

*P.C.*

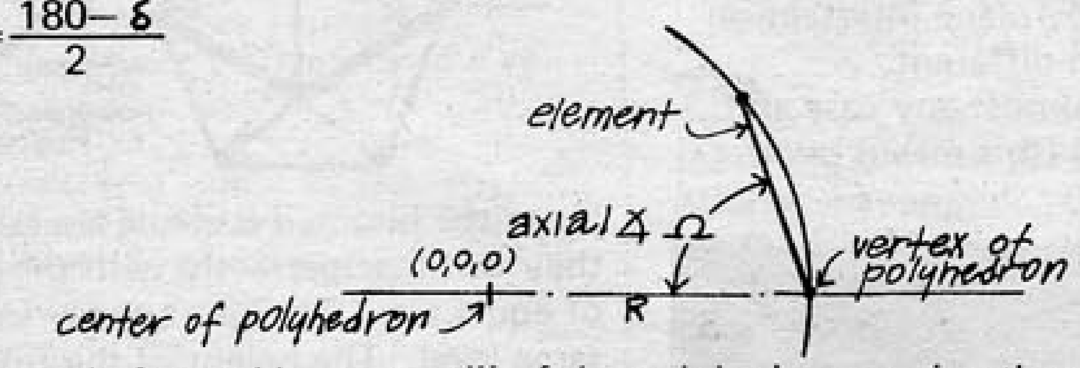
# Geodesic Math

Joseph D. Clinton

## BASIC DEFINITIONS

Axial angle (omega $\Omega$) = an angle formed by an element and a radius from the center of the polyhedron meeting in a common point. The vertex of the axial angle is chosen as that point common to the polyhedron element and radius.

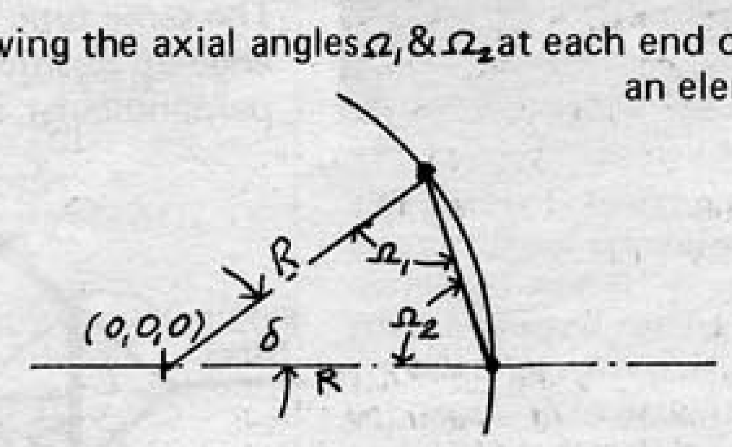
The axial angle $\Omega$ may be found if the central angle $\delta$ is known by the following equation: $= \frac{180-\delta}{2}$




Central angle (delta $\delta$) = an angle formed by two radii of the polyhedron passing through the end points of an element of the polyhedron. The vertex of the central angle is chosen as that point common to both radii (the center of the polyhedron).

The central angle $\delta$ may be found by knowing the axial angles $\Omega_1$ & $\Omega_2$ at each end of an element.

$\delta = 180 - (\Omega_1 + \Omega_2)$



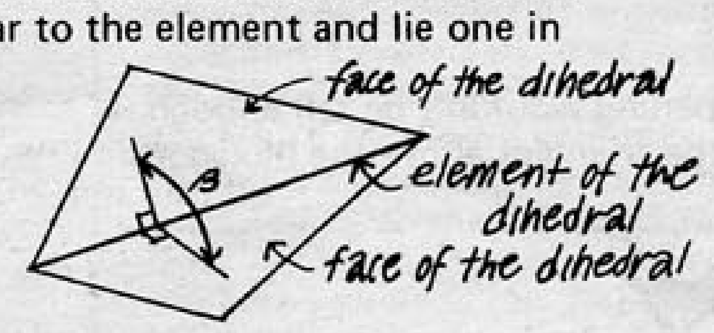

Chord factor (cf) = the element lengths calculated based on a radius of a non-dimensional unit of one for the spherical form with the end points of the elements coincident with the surface of the sphere.

If the central angle $\delta$ is known the chord factor may be calculated as follows: $cf = 2 \sin\frac{\delta}{2}$

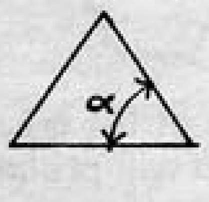
The length of any element for larger structures may be found by the equation: $l = cf \times r$

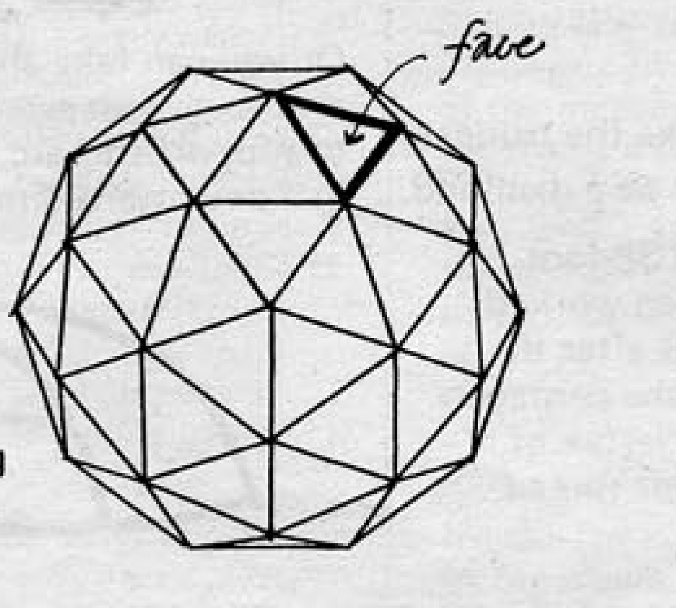
where: r = the radius of the desired structural form
l = the length of the new element

Dihedral angle (beta $\beta$) = an angle formed by two planes meeting in a common line. The two planes themselves are faces of the dihedral angle, and the element is the common line. To measure the dihedral angle measure the angle whose vertex is on the element of the dihedral angle and whose sides are perpendicular to the element and lie one in each face of the dihedral angle.



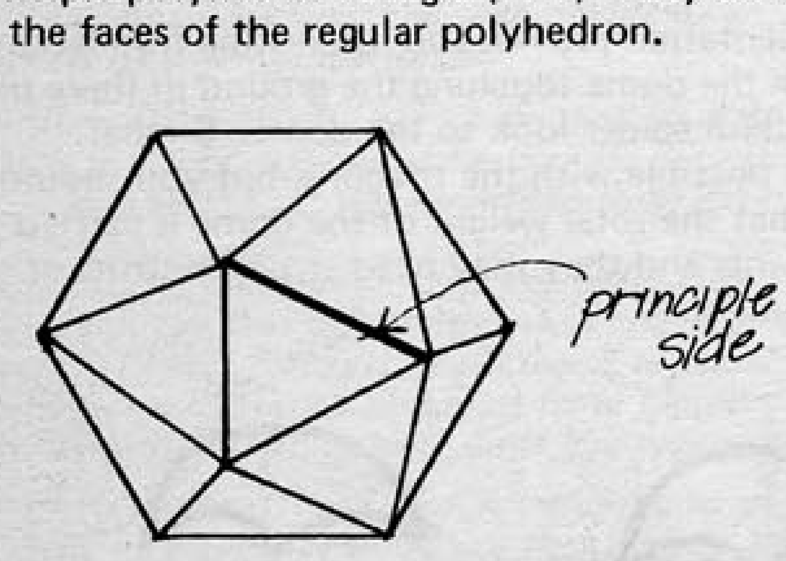

Face angle (alpha $\alpha$) = an angle formed by two elements meeting in a common point and lying in a plane that is one of the faces of the polyhedron.

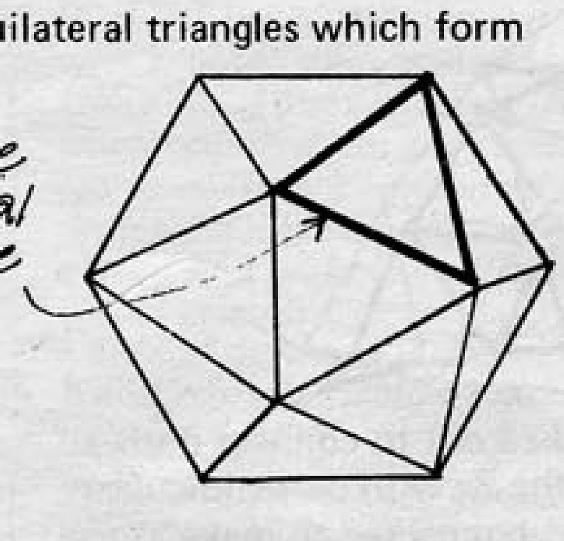



Face = any of the plane polygons making up the surface of the structural form.

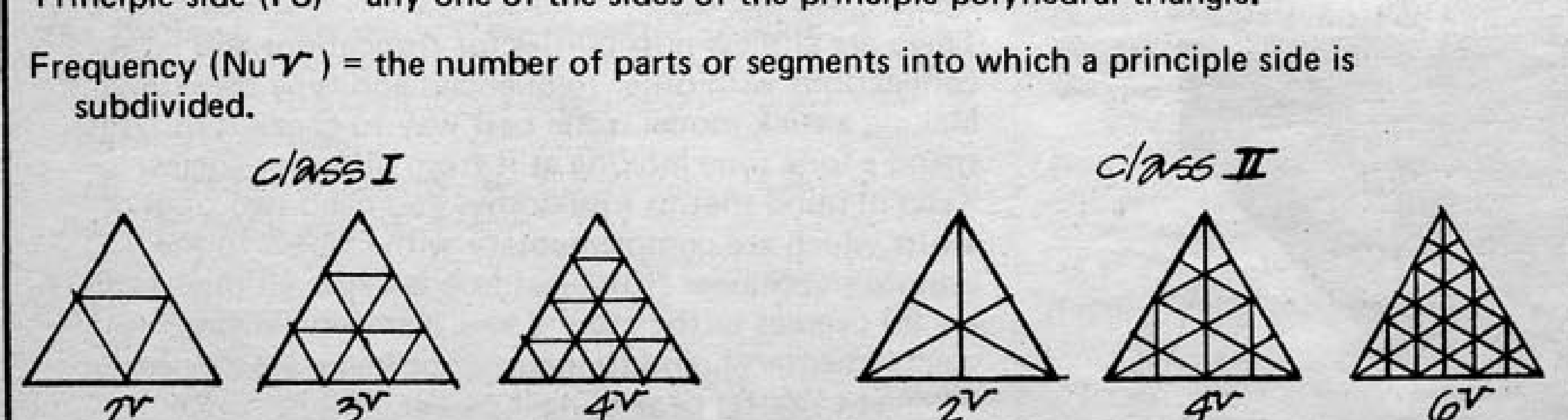
Principle polyhedral triangle (PPT) = any one of the plane equilateral triangles which form the faces of the regular polyhedron.




Principle side (PS) = any one of the sides of the principle polyhedral triangle.

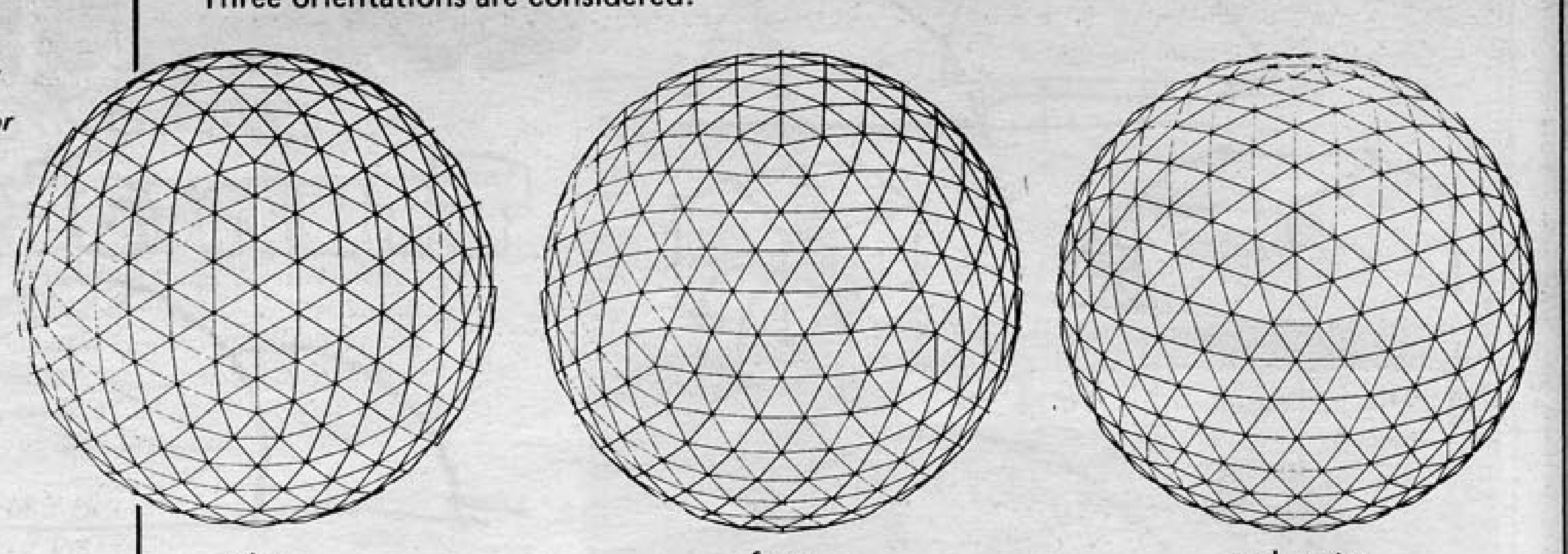
Frequency (Nu $\nu$) = the number of parts or segments into which a principle side is subdivided.






Orientation = the orientation the polyhedral form has in space with respect to the observer.

Three orientations are considered:



edge | face | and vertex.

## METHODS OF GENERATING 3-WAY GEODESIC GRIDS

Upon using the spherical form as a structural unit, it is apparent that the basic polyhedral form, in its fundamental state, can not satisfy the range of conditions that must be geometrically and structurally met. There have been many methods developed for reducing the basic polyhedral form into a larger number of components from which the geometrical properties may be made to remain within the structural fabrication and erection limits for a desired configuration.

Several methods of generating 3-way geodesic grids are discussed here in a broad sense to give the experimenter a basis from which other methods may be developed.

The methods described here may be considered as having characteristics of one of the two following classifications:

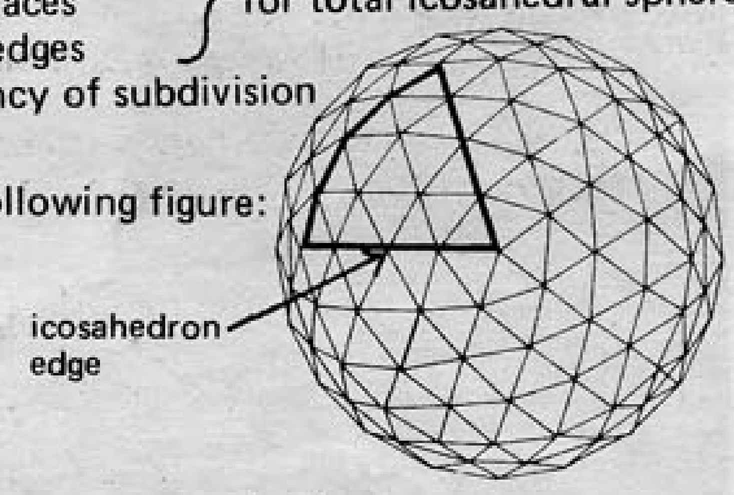
Class I:

- based on regular polyhedral forms, most generally the icosahedron.
- frequency of subdivision may be odd or even.

$V = 10\nu^2 + 2$
$F = 20\nu^2$
$E = 30\nu^2$

where:
V = no. of vertices
F = no. of faces
E = no. of edges
} for total icosahedral sphere
$\nu$ = frequency of subdivision

- demonstrates symmetries as illustrated in following figure:



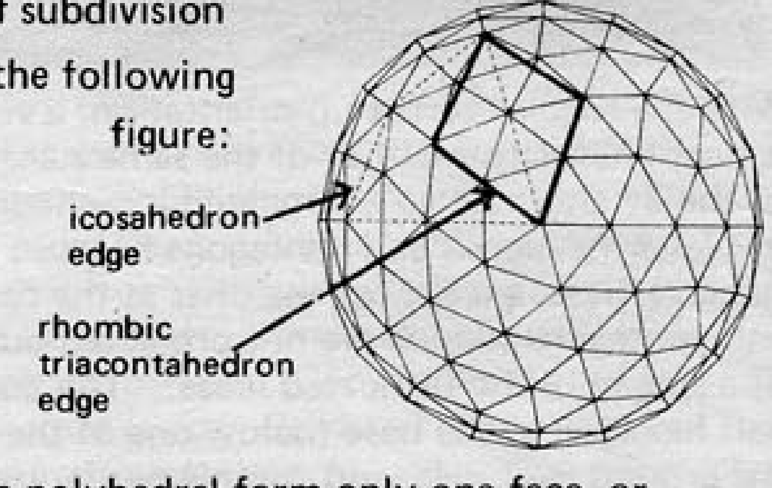

Class II:

- based on the quasi-regular polyhedral forms, most generally the rhombic triacontahedron.
- frequency of subdivision may only be even.

$V = n + 2$
$F = 2(n)$
$E = 3(n)$

where: $n = \frac{15\nu^2}{2}$
V = no. of vertices
F = no. of faces
E = no. of edges
} for total rhombic triacontahedral sphere
$\nu$ = frequency of subdivision

- demonstrates symmetries as illustrated in the following figure:



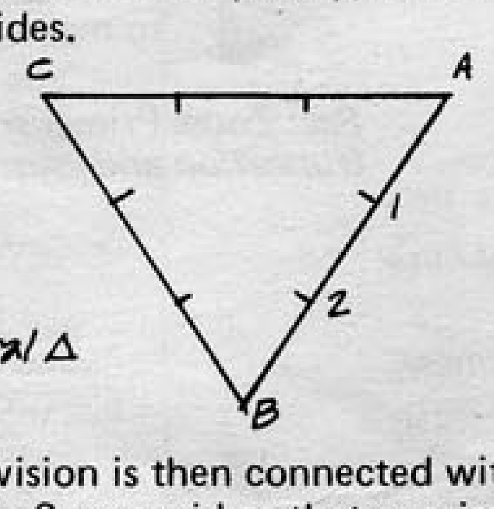

Due to the symmetrical characteristics of the basic polyhedral form only one face, or portions of one face, of the polyhedron is used for calculating the geometrical properties of the structural configuration. The remaining faces may be found by rotations and/or reflections of this principle polyhedral triangle and its transformations.

## CLASS I

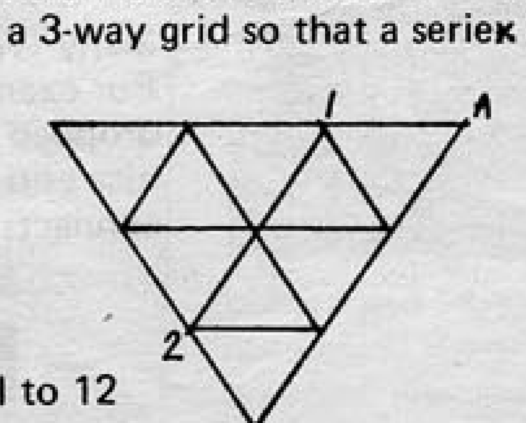
Method 1: *[This method is what was published in* Domebook One *under the name "alternate"; and is the geometry of the Pacific Dome, Aluminum Sun Dome, Pillow Dome, etc.]*

The PPT is subdivided into n frequency, with the parts chosen as equal divisions along the three principle sides.

Note: $\overline{A1} = \overline{12}$
△ ABC is a plane equilateral △

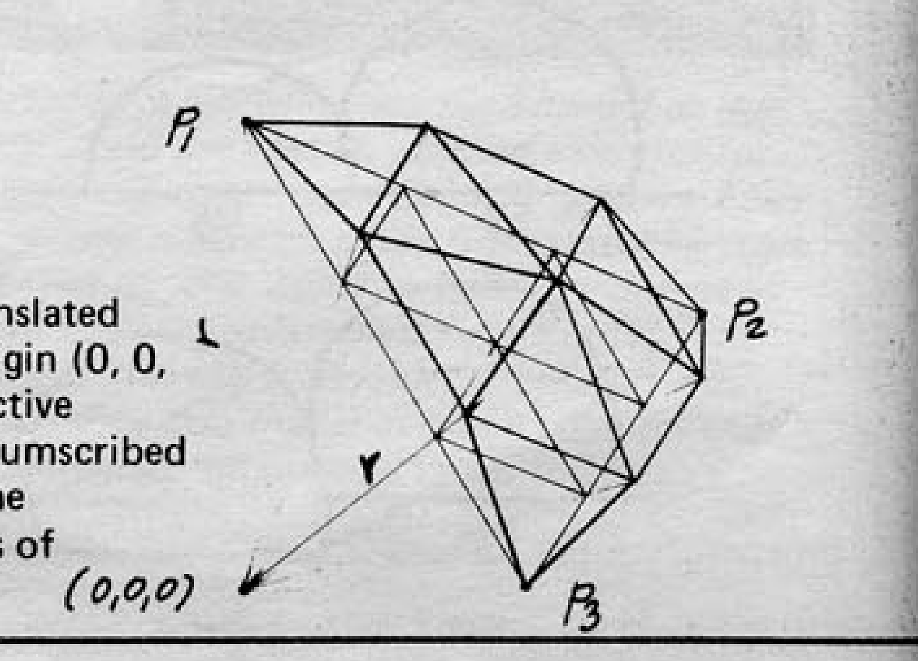



Each point of subdivision is then connected with a line segment parallel to their respective sides thereby giving a 3-way grid so that a series of equilateral triangles are formed.



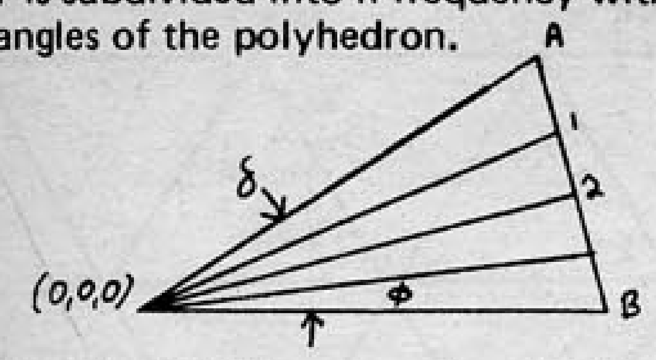

Note: AB is parallel to 12

Each vertex on the PPT is then translated along a line passing through the origin (0, 0, 0) of the polyhedron and its respective vertex, onto the surface of the circumscribed sphere. The element connecting the translated vertices form the chords of a 3-way great circular grid.



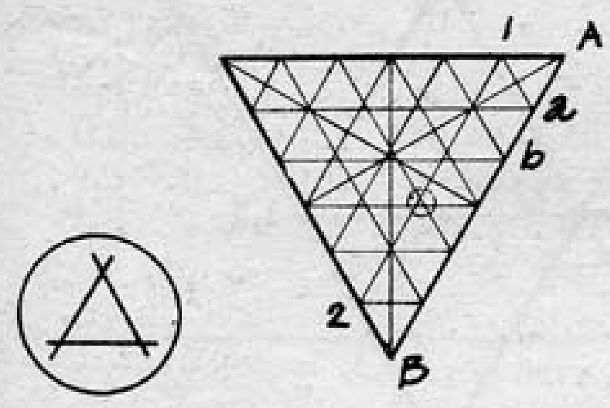
Method 2: *[This method produces equal divisions along the spherical PPT and results in, for example, 3 different triangles in the 3 with 3 strut lengths. Method I has 2 triangles and 3 struts]*

The PPT is subdivided into n frequency with the parts chosen as equal arc divisions of the central angles of the polyhedron.



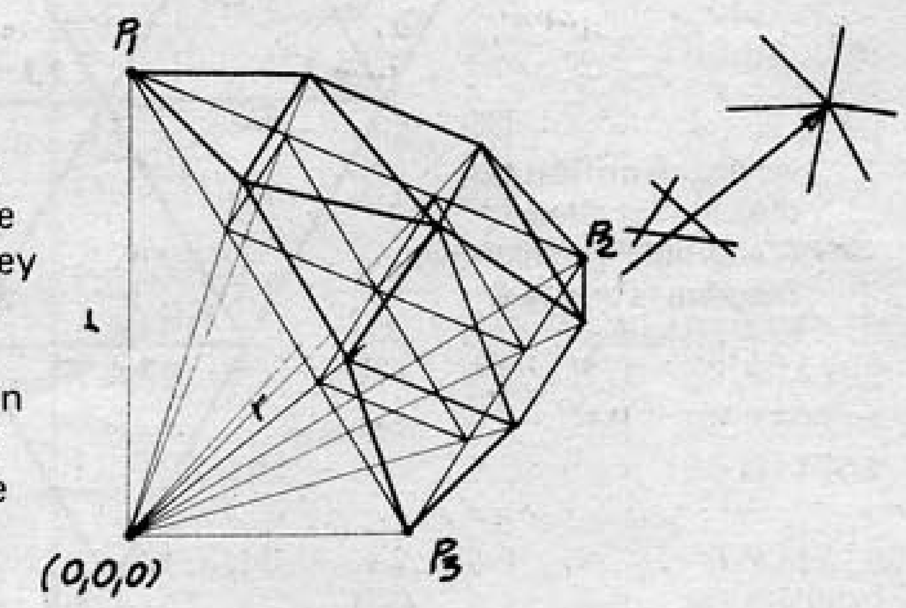

Note: $A1 \neq 12$

The points of subdivision on each principle side of the PPT are connected with line segments parallel to their respective sides. Each line segment intersects at a number of points which define a grid of subdivision. Due to the method of subdivision, small equilateral triangular "windows" occur in the grid.




Note: AB is parallel to 12
$Aa \neq ab$
Windows are equilateral triangles

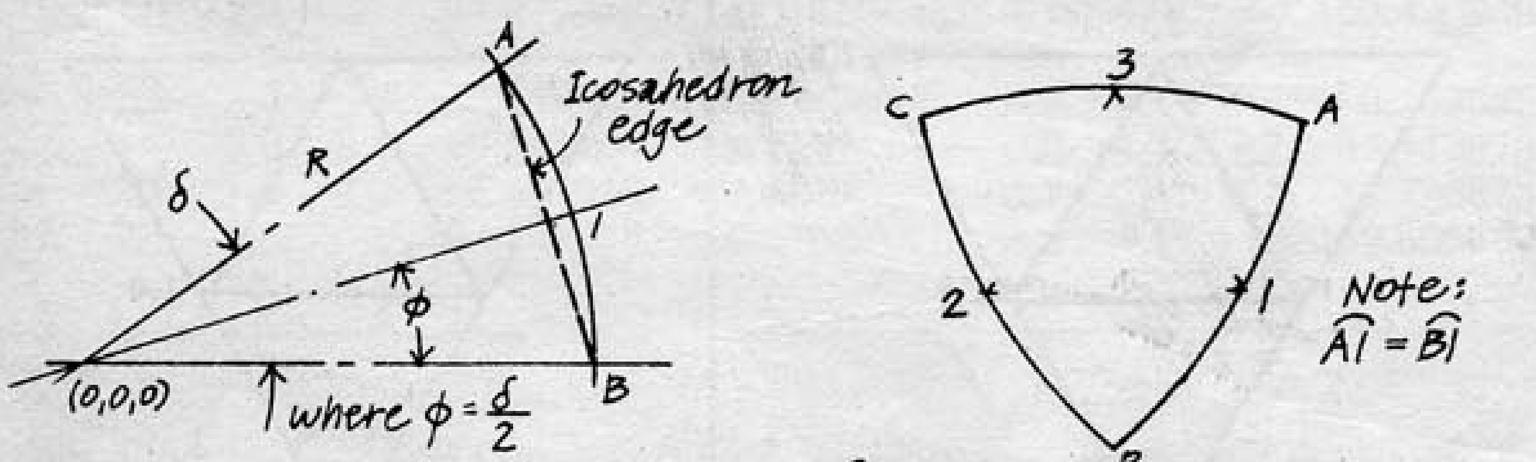
The centers of these "windows" are found on the plane of the PPT and are used as the vertices of the 3-way grid for the PPT. They are then translated onto the surface of the circumscribed sphere along a line passing through the respective vertex and the origin (0, 0, 0) of the polyhedron. The elements connecting the translated vertices form the chords of a 3-way great circular grid.



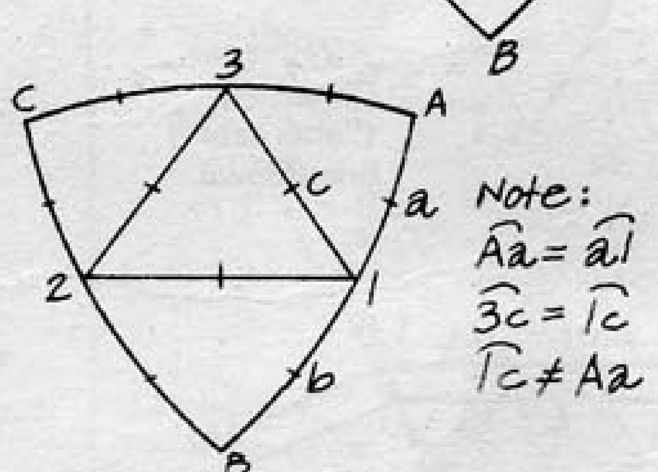

Method 3:

This method is sometimes referred to as the alternate geodesic grid. Usually, it is developed by starting with a small frequency and then subdividing further to the desired frequency by following a geometrical progression as per example:

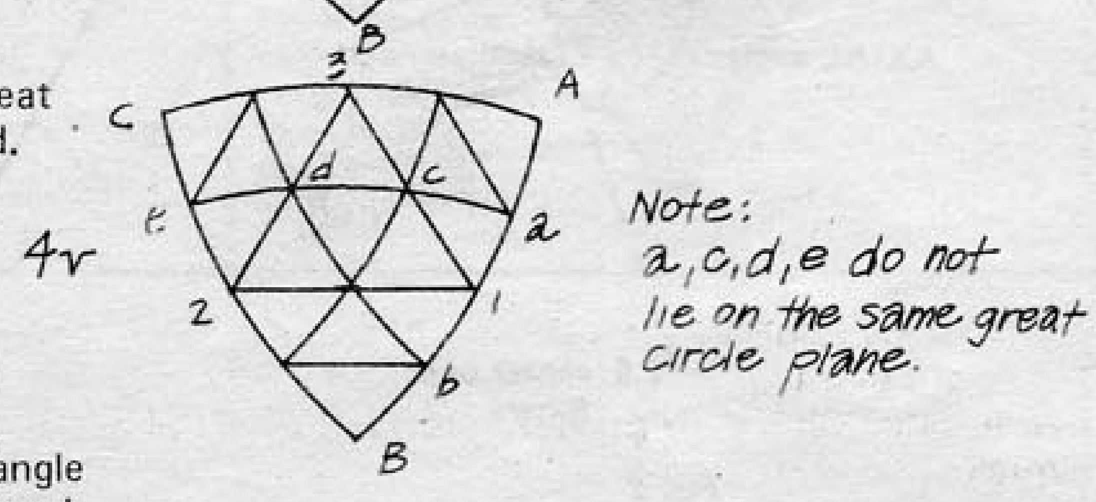
i.e., the spherical polyhedral triangle is subdivided into a low frequency subdivision, i.e. 2v, with parts chosen as equal arc divisions of the central angle of the polyhedron.



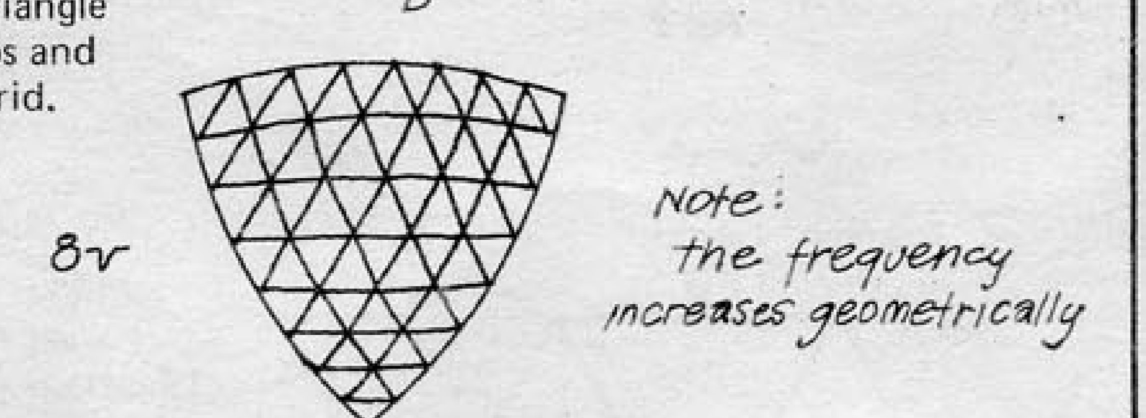

The interior points are found by passing great circle arcs through the previously found mid points of each principle side and finding the mid points of each side of each new triangle in the same manner as above.




Each point is then connected with great circle arcs to complete the 3-way grid.




For further subdivisons each new triangle is subdivided as in the previous steps and connected to complete the 3-way grid.




By knowing the central angles (δ) the chord factors may be calculated by the following equation:

cf = 2 (sin δ /2  where
cf = chord factor
δ = central angle

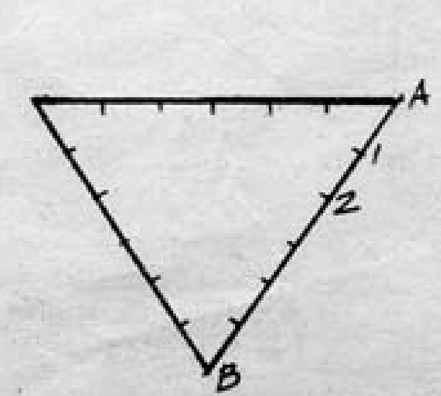
Method 4:

This method is an alteration of methods 1-3 allowing for truncation within the equatorial zone of the spherical form. It is developed with lesser circle as well as great circle arcs so that truncation may be done without requiring special elements. A set of parallel planes, falling in the equatorial region, are provided through the geodesic sphere, perpendicular to any given polar axis. Due to the less symmetrical characteristics of this method it is used primarily for small frequency structures. The number of relative differences in edge lengths are greater than any of the other methods.

## CLASS II

Method 1:

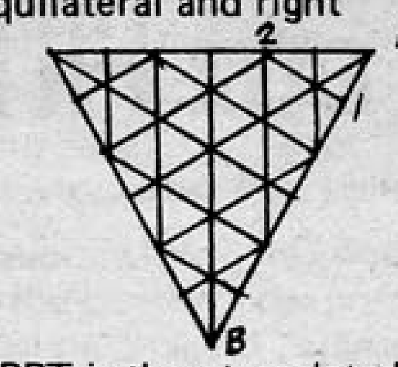
The PPT is subdivided into n frequency, with the parts chosen as equal divisions along the three principle sides.

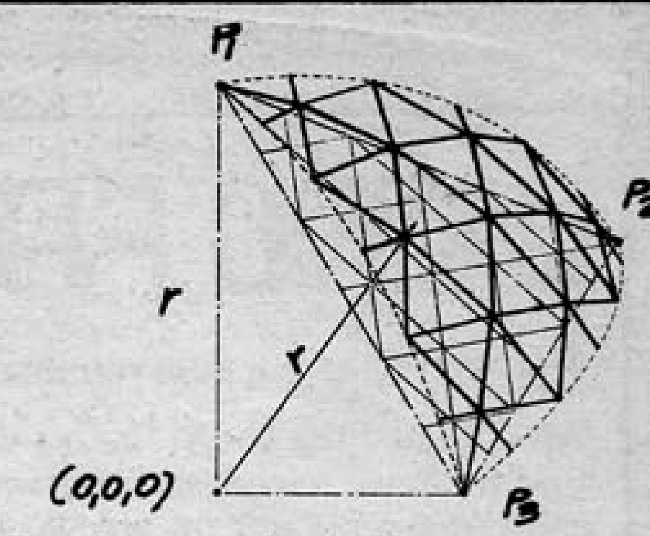



Note: $\overline{A1} = \overline{12}$

Each point of subdivisions is then connected with line segments perpendicular to their respective principle side thus giving a 3-way grid comprised of equilateral and right triangles.

Note: $\overline{AB} \perp \overline{12}$

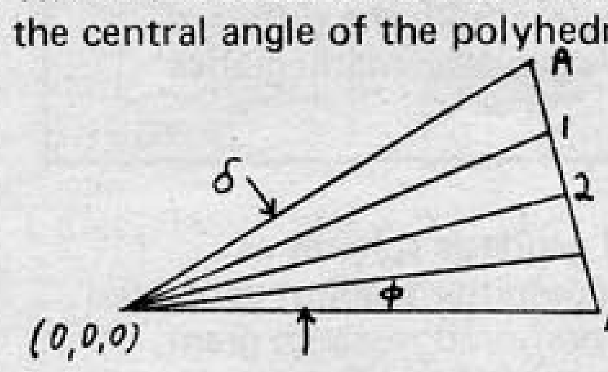


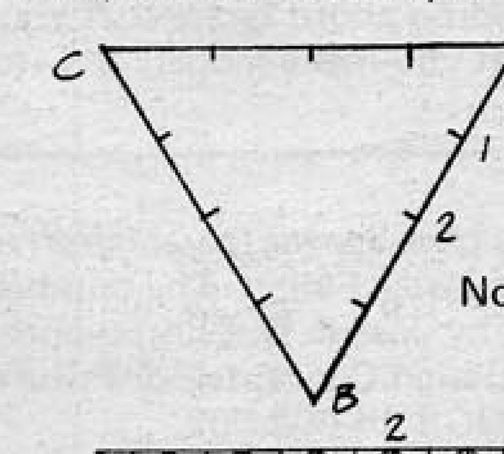




Each vertex on the PPT is then translated onto the surface of the circumscribed sphere along a line passing through the respective vertex and the origin (0, 0, 0) of the polyhedron. The elements connecting the translated vertex form the chords of a 3-way great circular grid.

Method 2:

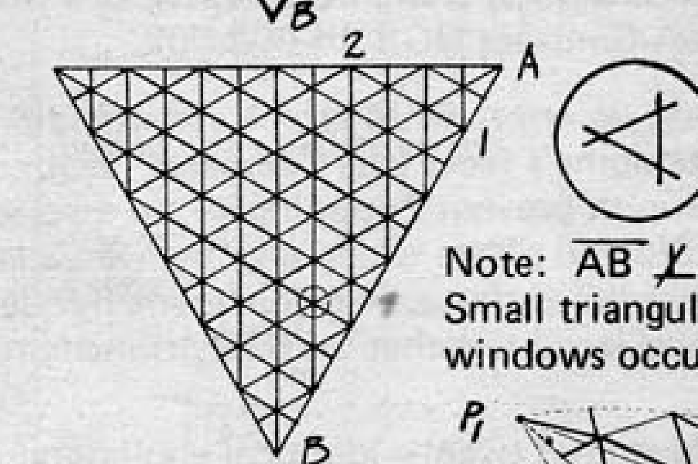
The PPT is subdivided into n frequency with the parts chosen as equal arc divisions of the central angle of the polyhedron.



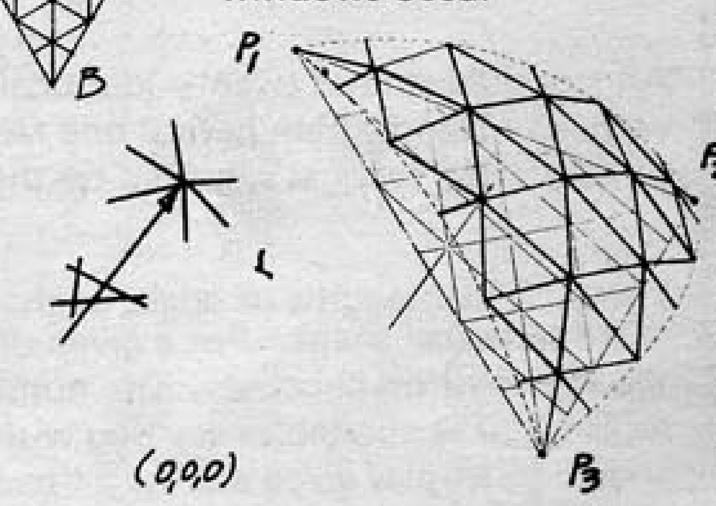

Note: $\overline{A1} \neq \overline{12}$

The points of subdivision on each principle side of the PPT are connected with line segments similar to method 1. However, the line segments are not perpendicular to their respective sides. Upon completion of the connections a grid is created. Due to the method of subdivision, small triangular "windows" occur in the grid.




Note: $\overline{AB} \not\perp \overline{12}$
Small triangular windows occur

The centers of these "windows" are found and are used as the vertices of a 3-way grid for the PPT. The vertices are then translated onto the surface of the circumscribed sphere along a line passing through the respective vertex and the origin (0, 0, 0) of the polyhedron. The elements joining the translated vertices form the chords of a 3-way great circle grid.

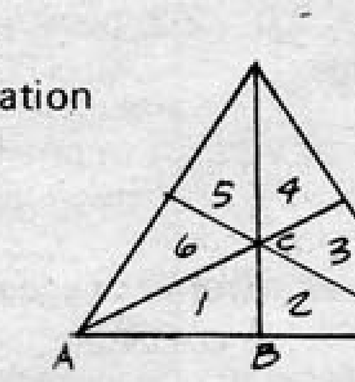



Method 3:

*[The chord factors and other data we published last year under the name "Triacon" were developed from this method. In general the triacon breakdown (Class II) is better for large domes because the number of different strut lengths increases arithmetically with the triacon (i.e., 6v has 6 different strut lengths, 8v has 8, 12v has 12 etc.) and geometrically with the alternate (Class I). For small frequency domes the difference is not that significant.]*

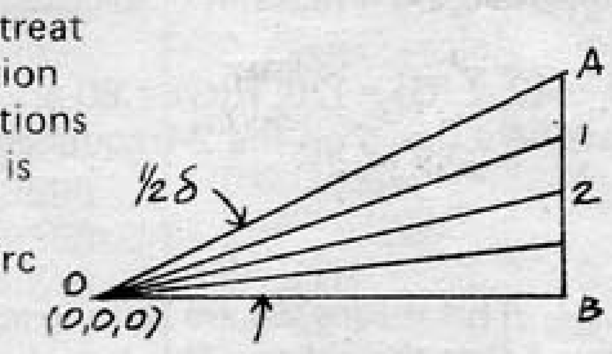
This method is sometimes referred to as the regular triacontahedral geodesic grid and was developed by Duncan Stuart.

The PPT may be described as six right triangles each being a reflection or rotation of the other.




Note: ABC is a right triangle

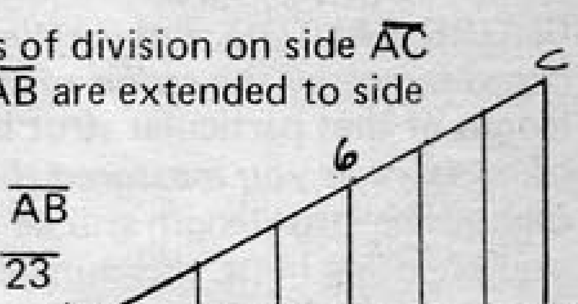
In this method of subdivision we shall treat only triangle ABC. The remaining section of the PPT may be found through rotations and reflections of this basic unit. This is true of all methods. The line $\overline{AB}$ is subdivided into parts chosen as equal arc divisions of the central angle of the polyhedron.




Note: $\overline{A1} \neq \overline{12}$

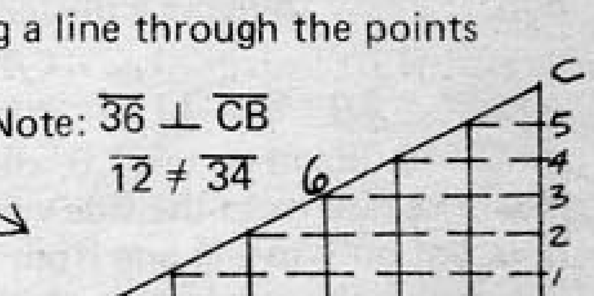
Once the subdivisions are found they are used to find the points of division on side $\overline{AC}$ and $\overline{CB}$. Perpendiculars through the points of division on side $\overline{AB}$ are extended to side $\overline{AC}$, this giving the points of subdivision on side $\overline{AC}$

Note: $\overline{36} \perp \overline{AB}$
$\overline{A1} \neq \overline{23}$

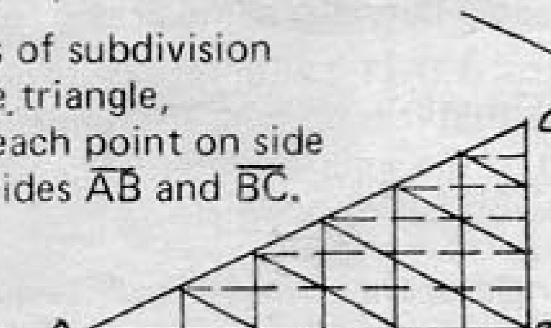



The points of division on the side $\overline{CB}$ were formed by extending a line through the points of subdivision on side $\overline{AC}$ perpendicular to side $\overline{CB}$.

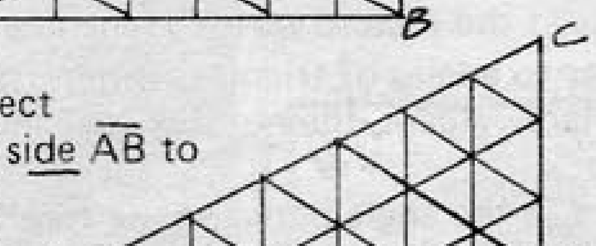
Note: $\overline{36} \perp \overline{CB}$
$\overline{12} \neq \overline{34}$



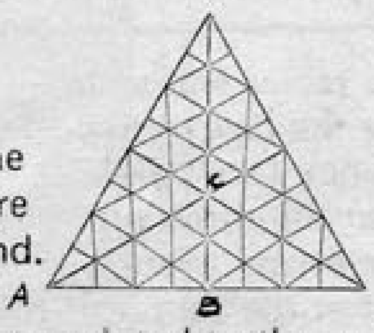

Having acquired the points of subdivision along the three sides of the triangle, diagonals are drawn from each point on side $\overline{AC}$ to alternate points of sides $\overline{AB}$ and $\overline{BC}$.

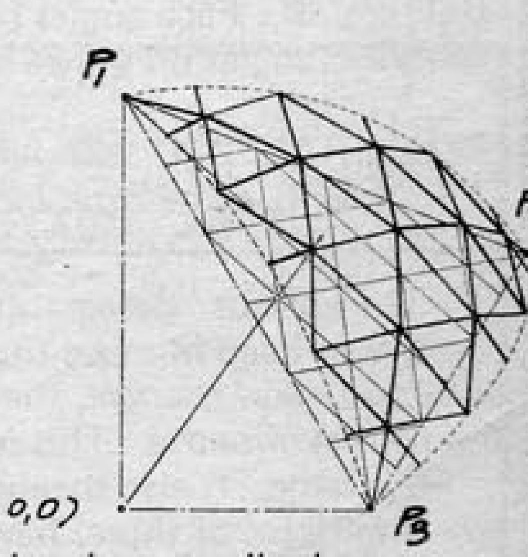



To complete the 3-way grid connect alternate points of subdivision of side $\overline{AB}$ to the points of division of side BC.




Through rotations and reflections of the basic unit and its subdivisions, the entire 3-way gridding of the PPT may be found.




The vertices of the 3-way grid are then translated to the surface of the circumscribed sphere along a line passing through the respective vertex and the origin (0, 0, 0) of the polyhedron. The elements joining the translated vertices form the chords of a 3-way great circle grid.

Method 4:

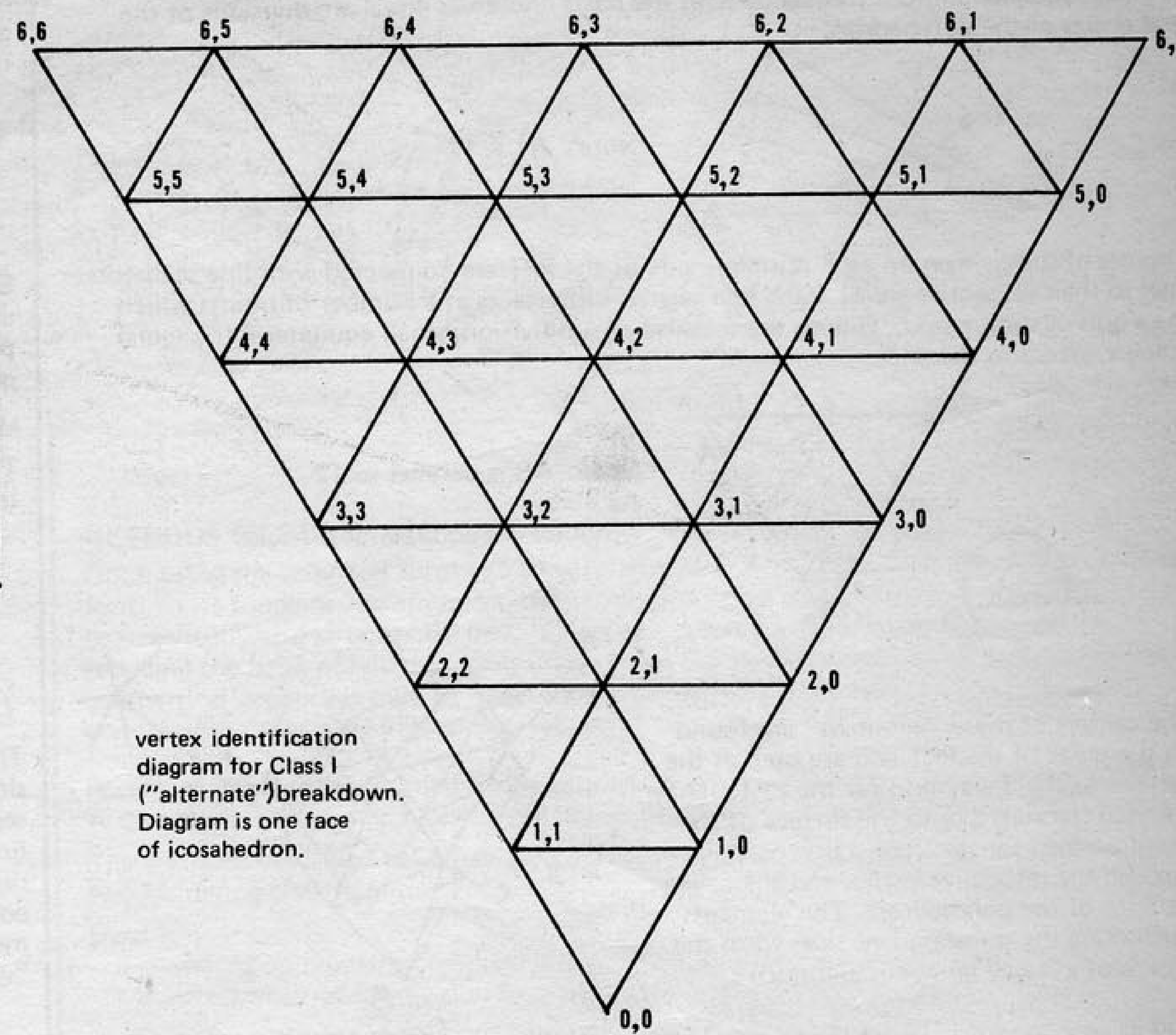
*[This method is basically the same as method 3 except that instead of dividing side AB of the right triangle with the equal arc divisions, side AC is divided. The rest of the procedure is the same, given the new starting point.]*

# CHORD FACTORS and ANGLES

A chord factor is a pure number which, when multiplied by a radius, gives a strut length.

We obtained the chord factors we printed in *Domebook One* from various sources. Since that time, we have made contact with Joseph D. Clinton who worked out the geodesic computer programs for NASA. What we called "alternate" breakdown in *Domebook One*, and in much of this book is classified in the computer programs as CLASS I. What we call "triacon" is CLASS II. In each class there are several methods, as described by Clinton on pp. 106-107. On the page opposite we are printing Class I, method 1- "alternate", the mathematics we have used for most of our domes. On p. 110, we are printing Class II, method 2, the math we have used in our "triacon" domes.

On p. 112 we are printing some alternative methods of both classes, and some tetrahedron and octahedron chord factors. If you want to explore fully the different methods we suggest that you make models and study Clinton's geodesic mathematics section.



vertex identification diagram for Class I ("alternate")breakdown. Diagram is one face of icosahedron.

Figures on the opposite page are for icosahedron based Class I geodesic spheres as discovered by R. Buckminster Fuller. The numbers are from computer readout generated by programs developed by Joseph D. Clinton under a NASA-sponsored research grant, "Advanced Structural Design Concepts For Future Space Missions," Final Report, March, 1970, NASA Contract NGR 14-008-002.

*Figures given do not refer to structural strength.* The higher the frequency, the flatter the angle of the dome's faces (the "dihedral" below) and the more critical is accurate workmanship to prevent "popping in" of a vertex under load. Big domes usually are made from folded plates which give the skin a large cross section, or they are made from two domes of the same or different frequencies but different size, one inside the other and laced together with additional struts, as at EXPO '67.

An icosahedron has twenty identical equilateral triangle faces and twelve pentagonal vertices. The diagram here is *one face* of the basic icosahedron (divided into the number of additional faces as required by the desired frequency.)

The different lengths of edges of these additional faces cause the icosa face to assume a more spherical shape. For a given diameter, the higher the frequency, the more sphere-like the icosahedron becomes. The numbers on the diagram are *vertex identifications,* and are referred to in the tables starting with 0,0. The following is an explanation of the tables, and all examples given are for a "two frequency" breakdown. Note that the diagram, regardless of what portion of it is used, *does not imply size.* Starting with the two frequency section:

2-FREQUENCY ICOSAHEDRON means a 2-frequency breakdown of a basic icosa.

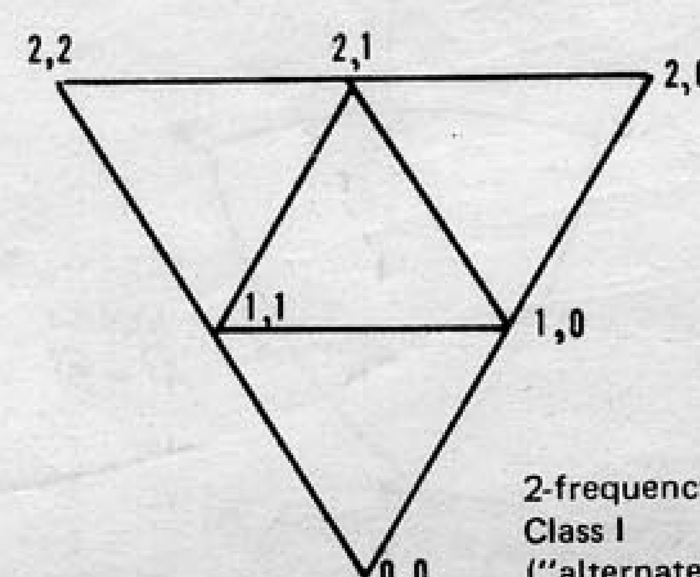
Looking at Fig. I, we see that for a 2-frequency breakdown, we use only that part part of the diagram outlined by 0,0 2,0 2,2, because that area represents *one icosa face* broken into *two parts* at the edge.

V(L)=6 means that the *number of vertices* in one icosa face of this particular breakdown is 6.

E(L)=9 means that the *number of edges* in one icosa face is 9.

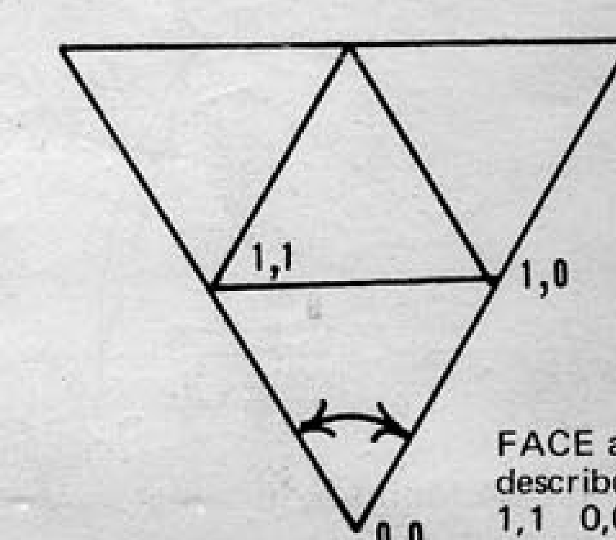
F(L)=4 means that there are 4 *faces* in one icosa face when broken into 2-frequency.

The figures V(G) = 42, E(G) = 120, F(G) = 80 are the number of vertices, edges, and faces in an *entire sphere* based on the 2-frequency breakdown of the basic icosa.



2-frequency Class I ("alternate") breakdown

*Fig. 1*



FACE angle described by 1,1 0,0 1,0

*Fig. 3*

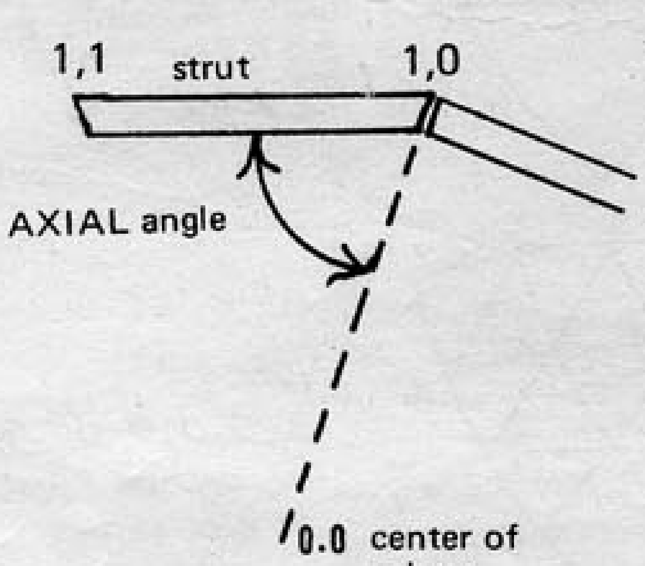
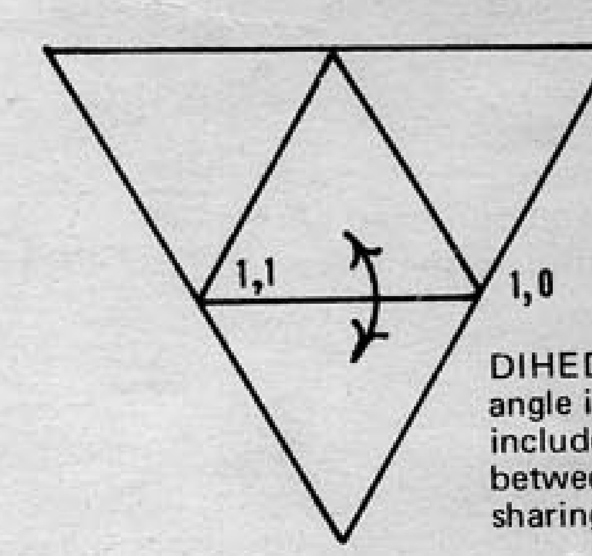


*Fig. 2*

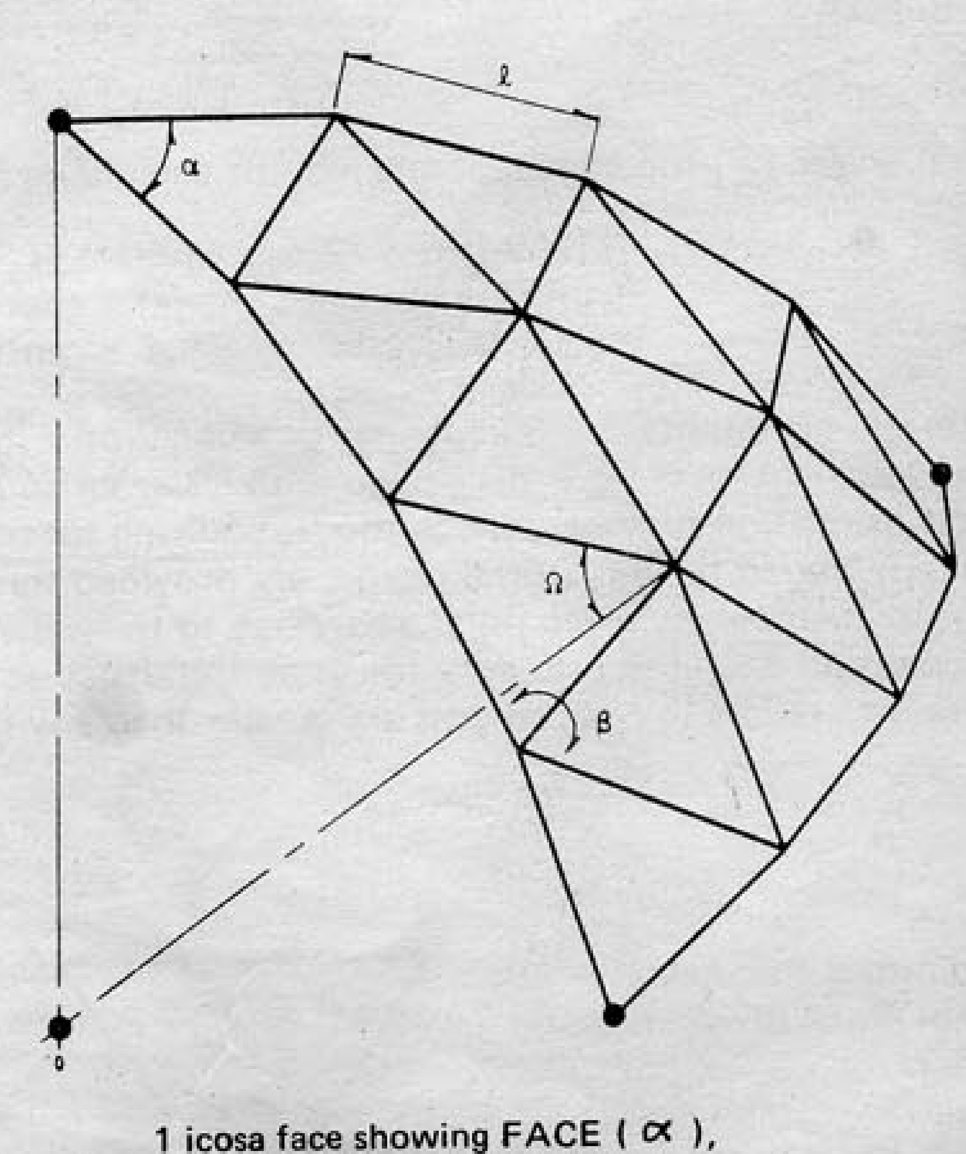


DIHEDRAL angle is total included angle between faces sharing 1,1 1,0

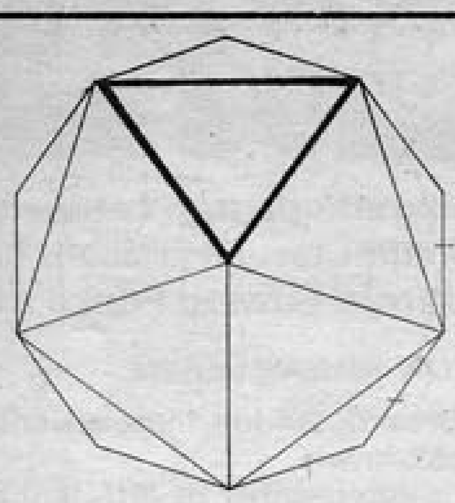
*Fig. 4*

- **LENGTH** 1,1 1,0 This means we are talking about the strut that has vertex 1,1 at one end and vertex 1,0 at the other. This length number is also known as the CHORD FACTOR, and is called that in the rest of this book. To use it, multiply this chord factor by the *radius* of the dome you want to build. The result will be the length of that particular strut in the size dome you desire; it will be in the *same unit of measure as you measured the radius.* In other words, if you give the radius in inches, the strut length will be given in inches. This length is *vertex to vertex.* If you are using hubs, this number will include the hubs, so the *actual cut length of the struts will be less than this number.* It will be this number *minus* the diameter of a hub. It's easy to make a mistake here. Think it out carefully, and again in the morning.
- **AXIAL** 0.0 1,0 1,1 refers to the angle between a line drawn from the center of the sphere (0.0) and vertex 1,0, and the strut 1,0 1,1 (Fig. 2). It is the angle that a strut meets its hub from the side view. Note that it is *not* the entire included angle under a hub, but only to the line from the hub to the sphere center. The value is DEGREES. 90° minus the axial angle equals angle you cut or bend struts.
- **FACE** 1,1 0,0 1,0 refers to one angle of the triangle described by these points. The angle given whose apex is at the second vertex identification shown; in this case, 0,0 (Fig. 3). Face angles refer to angles of triangles generated by chord factors, not spherical angles on a true sphere. Again, the number is given in degrees.
- **DIHEDRAL** 1,1 1,0 refers to the angle between the two faces that share edge 1,1 1,0. It is the *total included angle* and again is given in degrees. See Fig. 4.

The various "paragraphs" in the tables will yield all the necessary information if you keep in mind that, just as the face in the original basic icosahedron was an *equilateral triangle,* the 2-frequency face 0,0 2,0 2,2 is *also equilateral and thus symmetric.* This means that the three triangles shaded in Fig. 5 are exactly the same. It also means that the center triangle is equilateral. 3-, 6-, 9-frequencies (multiples of three) have a point at the center of the face instead of a triangle as in this case. Figs 6 and 7 show the 3 and 4 frequency breakdowns. The triangles of the same shading are the same in all respects except left and right orientation. Note that the pattern of sameness is symmetric about the center of the triangular array of whatever breakdown frequency you are using.



1 icosa face showing FACE ( $\alpha$ ), AXIAL ( $\Omega$ ), and DIHEDRAL ( $\beta$ ) angles.

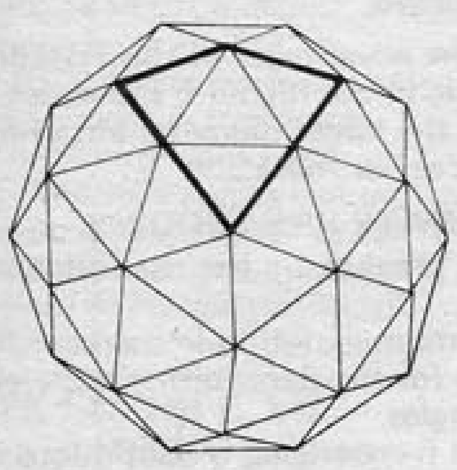


**1-FREQUENCY ICOSAHEDRON class 1 method 1**

V(L) = 3, E(L) = 3 F(L) = 1

V(G) = 12 E(G) = 30 F(G) = 20

| | | | | |
|---|---|---|---|---|
| LENGTH | 1,1 | 1,0 | | 1.05146222 |
| AXIAL | 0.0 | 1,0 | 1,1 | 58.282525 |
| FACE | 1,1 | 0,0 | 1,0 | 59.999998 |
| DIHEDRAL | 1,1 | 1,0 | | 138.189684 |

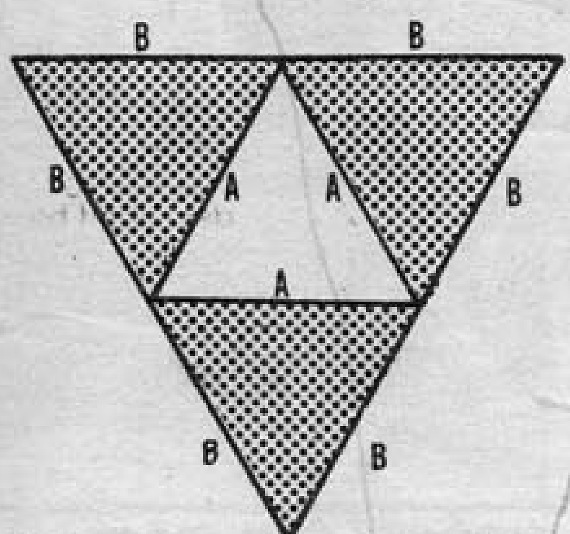


**2-FREQUENCY ICOSAHEDRON class 1 method 1**

V(L) = 6 E(L) = 9 F(L) = 4

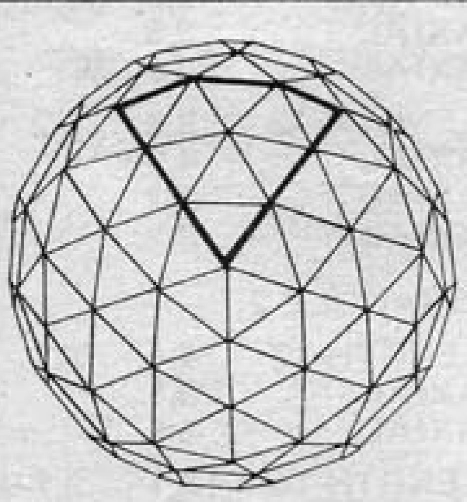
V(G) = 42 E(G) = 120 F(G) = 80

| | | | | |
|---|---|---|---|---|
| LENGTH A | 1,1 | 1,0 | | 0.61803399 |
| AXIAL | 0.0 | 1,0 | 1,1 | 71.999996 |
| FACE | 1,1 | 0,0 | 1,0 | 68.861974 |
| FACE | 1,1 | 2,1 | 1,0 | 59.999998 |
| DIHEDRAL | 1,1 | 1,0 | | 161.970892 |
| LENGTH B | 2,1 | 2,0 | | 0.54653306 |
| AXIAL | 0.0 | 2,0 | 2,1 | 74.141260 |
| FACE | 2,1 | 1,0 | 2,0 | 55.569010 |
| DIHEDRAL | 2,1 | 2,0 | | 157.541075 |



2-frequency. shaded faces are identical

*Fig. 5*

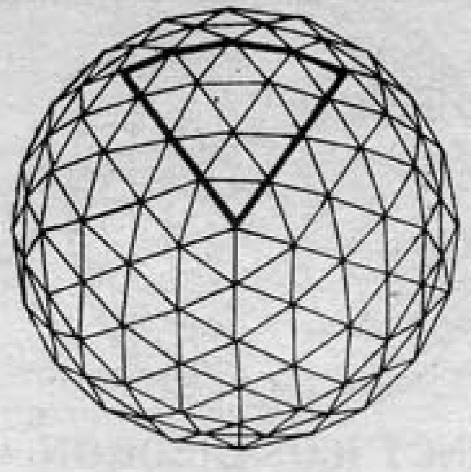


**3-FREQUENCY ICOSAHEDRON class 1 method 1**

V(L) = 10 E(L) = 18 F(L) = 9

V(G) = 92 E(G) = 270 F(G) = 180

| | | | | |
|---|---|---|---|---|
| LENGTH B | 1,1 | 1,0 | | 0.40354821 |
| AXIAL | 0.0 | 1,0 | 1,1 | 78.359272 |
| FACE | 1,1 | 0,0 | 1,0 | 70.730537 |
| FACE | 1,1 | 2,1 | 1,0 | 58.583164 |
| DIHEDRAL | 1,1 | 1,0 | | 168.641064 |
| LENGTH C | 2,1 | 2,0 | | 0.41241149 |
| AXIAL | 0.0 | 2,0 | 2,1 | 78.099906 |
| FACE | 2,1 | 1,0 | 2,0 | 60.708416 |
| FACE | 2,1 | 3,1 | 2,0 | 60.708416 |
| DIHEDRAL | 2,1 | 2,0 | | 166.421442 |
| LENGTH A | 3,1 | 3,0 | | 0.34861548 |
| AXIAL | 0.0 | 3,0 | 3,1 | 79.961621 |
| FACE | 3,1 | 2,0 | 3,0 | 54.634727 |
| DIHEDRAL | 3,1 | 3,0 | | 165.564739 |
| LENGTH B | 3,2 | 3,1 | | 0.40354822 |
| AXIAL | 0.0 | 3,1 | 3,2 | 78.359272 |
| FACE | 3,2 | 2,1 | 3,1 | 58.583164 |
| DIHEDRAL | 3,2 | 3,1 | | 165.542280 |

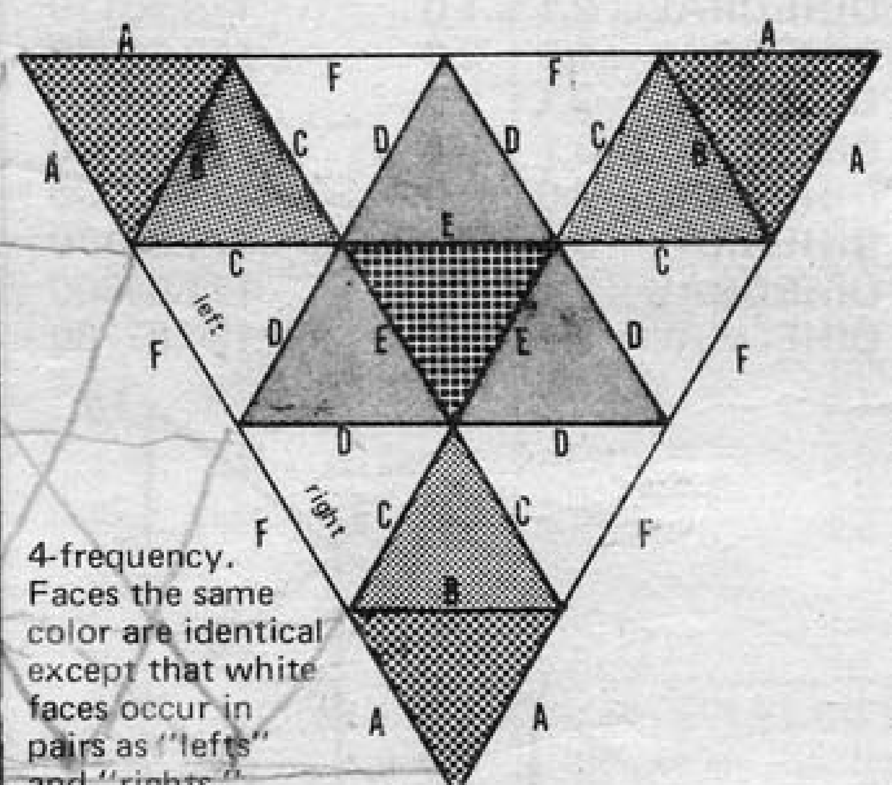


**4-FREQUENCY ICOSAHEDRON class 1 method 1**

V(L) = 15 E(L) = 30 F(L) = 16

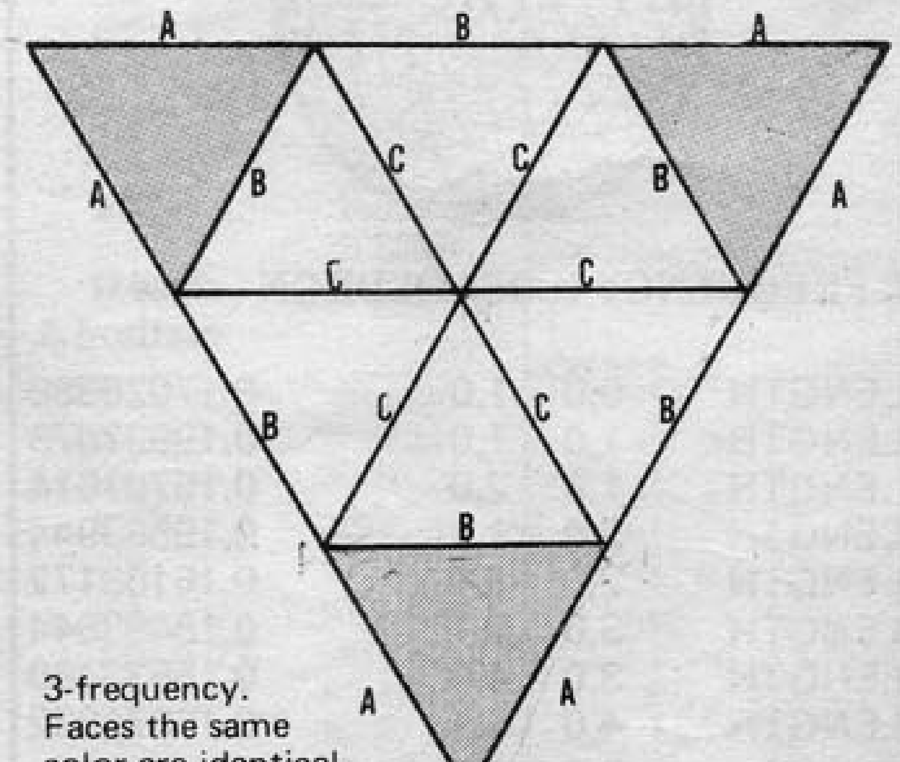
V(G) = 162 E(G) = 480 F(G) = 320

| | | | | |
|---|---|---|---|---|
| LENGTH B | 1,1 | 1,0 | | 0.29524181 |
| AXIAL | 0.0 | 1,0 | 1,1 | 81.510921 |
| FACE | 1,1 | 0,0 | 1,0 | 71.331604 |
| FACE | 1,1 | 2,1 | 1,0 | 60.159766 |
| DIHEDRAL | 1,1 | 1,0 | | 172.197790 |
| LENGTH D | 2,1 | 2,0 | | 0.31286893 |
| AXIAL | 0.0 | 2,0 | 2,1 | 80.999996 |
| FACE | 2,1 | 1,0 | 2,0 | 63.668768 |
| FACE | 2,1 | 3,1 | 2,0 | 58.717473 |
| DIHEDRAL | 2,1 | 2,0 | | 169.981901 |
| LENGTH C | 3,1 | 3,0 | | 0.29453084 |
| AXIAL | 0.0 | 3,0 | 3,1 | 81.531510 |
| FACE | 3,1 | 2,0 | 3,0 | 57.534353 |
| FACE | 3,1 | 4,1 | 3,0 | 59.920114 |
| DIHEDRAL | 3,1 | 3,0 | | 169.617161 |
| LENGTH E | 3,2 | 3,1 | | 0.32491969 |
| AXIAL | 0.0 | 3,1 | 3,2 | 80.650292 |
| FACE | 3,2 | 2,1 | 3,1 | 59.999999 |
| FACE | 3,2 | 4,2 | 3,1 | 62.565048 |
| DIHEDRAL | 3,2 | 3,1 | | 169.642082 |
| LENGTH A | 4,1 | 4,0 | | 0.25318459 |
| AXIAL | 0.0 | 4,0 | 4,1 | 82.727277 |
| FACE | 4,1 | 3,0 | 4,0 | 54.334194 |
| DIHEDRAL | 4,1 | 4,0 | | 169.490046 |
| LENGTH F | 4,2 | 4,1 | | 0.29858813 |
| AXIAL | 0.0 | 4,1 | 4,2 | 81.413979 |
| FACE | 4,2 | 3,1 | 4,1 | 58.796873 |
| DIHEDRAL | 4,2 | 4,1 | | 169.505737 |



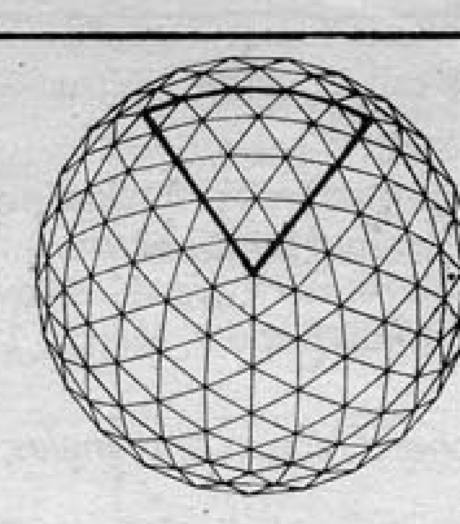
4-frequency. Faces the same color are identical except that white faces occur in pairs as "lefts" and "rights."

*Fig. 7*



3-frequency. Faces the same color are identical

*Fig. 6*

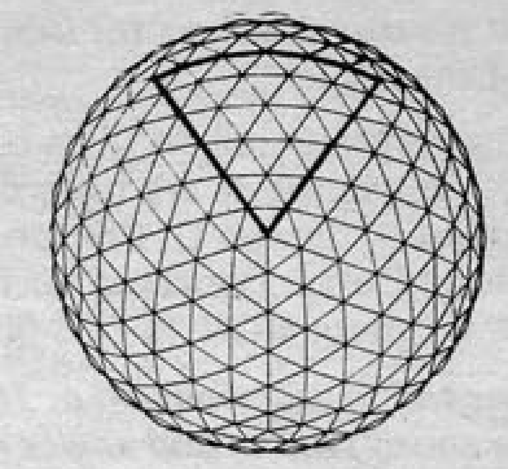


**5-FREQUENCY ICOSAHEDRON class 1 method 1**

V(L) = 21 E(L) = 45 F(L) = 25

V(G) = 252 E(G) = 750 F(G) = 500

| | | | | |
|---|---|---|---|---|
| LENGTH | 1,1 | 1,0 | | 0.23179025 |
| AXIAL | 0.0 | 1,0 | 1,1 | 83.344741 |
| FACE | 1,1 | 0,0 | 1,0 | 71.590918 |
| FACE | 1,1 | 2,1 | 1,0 | 61.797728 |
| DIHEDRAL | 1,1 | 1,0 | | 174.186995 |
| LENGTH | 2,1 | 2,0 | | 0.24724291 |
| AXIAL | 0.0 | 2,0 | 2,1 | 82.898845 |
| FACE | 2,1 | 1,0 | 2,0 | 65.444659 |
| FACE | 2,1 | 3,1 | 2,0 | 59.197807 |
| DIHEDRAL | 2,1 | 2,0 | | 172.477804 |
| LENGTH | 3,1 | 3,0 | | 0.24508578 |
| AXIAL | 0.0 | 3,0 | 3,1 | 82.961115 |
| FACE | 3,1 | 2,0 | 3,0 | 59.964814 |
| FACE | 3,1 | 4,1 | 3,0 | 58.369323 |
| DIHEDRAL | 3,1 | 3,0 | | 171.544544 |
| LENGTH | 3,2 | 3,1 | | 0.26159810 |
| AXIAL | 0.0 | 3,1 | 3,2 | 82.484227 |
| FACE | 3,2 | 2,1 | 3,1 | 61.674566 |
| FACE | 3,2 | 4,2 | 3,1 | 59.999997 |
| DIHEDRAL | 3,2 | 3,1 | | 171.553503 |
| LENGTH | 4,1 | 4,0 | | 0.22568578 |
| AXIAL | 0.0 | 4,0 | 4,1 | 83.520774 |
| FACE | 4,1 | 3,0 | 4,0 | 56.125012 |
| FACE | 4,1 | 5,1 | 4,0 | 59.101135 |
| DIHEDRAL | 4,1 | 4,0 | | 171.730190 |
| LENGTH | 4,2 | 4,1 | | 0.25516701 |
| AXIAL | 0.0 | 4,1 | 4,2 | 82.670021 |
| FACE | 4,2 | 3,1 | 4,1 | 59.162712 |
| FACE | 4,2 | 5,2 | 4,1 | 62.432868 |
| DIHEDRAL | 4,2 | 4,1 | | 171.745039 |
| LENGTH | 5,1 | 5,0 | | 0.19814743 |
| AXIAL | 0.0 | 5,0 | 5,1 | 84.314162 |
| FACE | 5,1 | 4,0 | 5,0 | 54.204537 |
| DIHEDRAL | 5,1 | 5,0 | | 171.765753 |
| LENGTH | 5,2 | 5,1 | | 0.23159760 |
| AXIAL | 0.0 | 5,1 | 5,2 | 83.350295 |
| FACE | 5,2 | 4,1 | 5,1 | 58.430325 |
| DIHEDRAL | 5,2 | 5,1 | | 171.783924 |
| LENGTH | 5,3 | 5,2 | | 0.24534642 |
| AXIAL | 0.0 | 5,2 | 5,3 | 82.953590 |
| FACE | 5,3 | 4,2 | 5,2 | 60.070368 |
| DIHEDRAL | 5,3 | 5,2 | | 171.838518 |



**6-FREQUENCY ICOSAHEDRON class 1 method 1**

V(L) = 28 E(L) = 63 F(L) = 36

V(G) = 362 E(G) = 1080 F(G) = 720

| | | | | |
|---|---|---|---|---|
| LENGTH | 1,1 | 1,0 | | 0.19047686 |
| AXIAL | 0.0 | 1,0 | 1,1 | 84.534954 |
| FACE | 1,1 | 0,0 | 1,0 | 71.724745 |
| FACE | 1,1 | 2,1 | 1,0 | 63.141629 |
| DIHEDRAL | 1,1 | 1,0 | | 175.412319 |
| LENGTH | 2,1 | 2,0 | | 0.20281969 |
| AXIAL | 0.0 | 2,0 | 2,1 | 84.179635 |
| FACE | 2,1 | 1,0 | 2,0 | 66.606874 |
| FACE | 2,1 | 3,1 | 2,0 | 60.244049 |
| DIHEDRAL | 2,1 | 2,0 | | 174.131815 |
| LENGTH | 3,1 | 3,0 | | 0.20590774 |
| AXIAL | 0.0 | 3,0 | 3,1 | 84.090703 |
| FACE | 3,1 | 2,0 | 3,0 | 61.807500 |
| FACE | 3,1 | 4,1 | 3,0 | 58.470501 |
| DIHEDRAL | 3,1 | 3,0 | | 173.178778 |
| LENGTH | 3,2 | 3,1 | | 0.21535373 |
| AXIAL | 0.0 | 3,1 | 3,2 | 83.818582 |
| FACE | 3,2 | 2,1 | 3,1 | 63.058991 |
| FACE | 3,2 | 4,2 | 3,1 | 59.611143 |
| DIHEDRAL | 3,2 | 3,1 | | 173.202995 |
| LENGTH | 4,1 | 4,0 | | 0.19801258 |
| AXIAL | 0.0 | 4,0 | 4,1 | 84.318046 |
| FACE | 4,1 | 3,0 | 4,0 | 57.948445 |
| FACE | 4,1 | 5,1 | 4,0 | 57.948447 |
| DIHEDRAL | 4,1 | 4,0 | | 172.856775 |
| LENGTH | 4,2 | 4,1 | | 0.21662821 |
| AXIAL | 0.0 | 4,1 | 4,2 | 83.781857 |
| FACE | 4,2 | 3,1 | 4,1 | 60.194424 |
| FACE | 4,2 | 5,2 | 4,1 | 60.194427 |
| DIHEDRAL | 4,2 | 4,1 | | 172.843306 |
| LENGTH | 5,1 | 5,0 | | 0.18190825 |
| AXIAL | 0.0 | 5,0 | 5,1 | 84.781497 |
| FACE | 5,1 | 4,0 | 5,0 | 55.403753 |
| FACE | 5,1 | 6,1 | 5,0 | 58.429183 |
| DIHEDRAL | 5,1 | 5,0 | | 173.170748 |
| LENGTH | 5,2 | 5,1 | | 0.20590773 |
| AXIAL | 0.0 | 5,1 | 5,2 | 84.090701 |
| FACE | 5,2 | 4,1 | 5,1 | 58.470502 |
| FACE | 5,2 | 6,2 | 5,1 | 61.807496 |
| DIHEDRAL | 5,2 | 5,1 | | 173.178770 |
| LENGTH | 5,3 | 5,2 | | 0.21535373 |
| AXIAL | 0.0 | 5,2 | 5,3 | 83.818583 |
| FACE | 5,3 | 4,2 | 5,2 | 59.611144 |
| FACE | 5,3 | 6,3 | 5,2 | 63.058989 |
| DIHEDRAL | 5,3 | 5,2 | | 173.202999 |
| LENGTH | 6,1 | 6,0 | | 0.16256722 |
| AXIAL | 0.0 | 6,0 | 6,1 | 85.337645 |
| FACE | 6,1 | 5,0 | 6,0 | 54.137622 |
| DIHEDRAL | 6,1 | 6,0 | | 173.240530 |
| LENGTH | 6,2 | 6,1 | | 0.18738340 |
| AXIAL | 0.0 | 6,1 | 6,2 | 84.623971 |
| FACE | 6,2 | 5,1 | 6,1 | 57.989368 |
| DIHEDRAL | 6,2 | 6,1 | | 173.254913 |
| LENGTH | 6,3 | 6,2 | | 0.20281970 |
| AXIAL | 0.0 | 6,2 | 6,3 | 84.179636 |
| FACE | 6,3 | 5,2 | 6,2 | 60.244049 |
| DIHEDRAL | 6,3 | 6,2 | | 173.318399 |

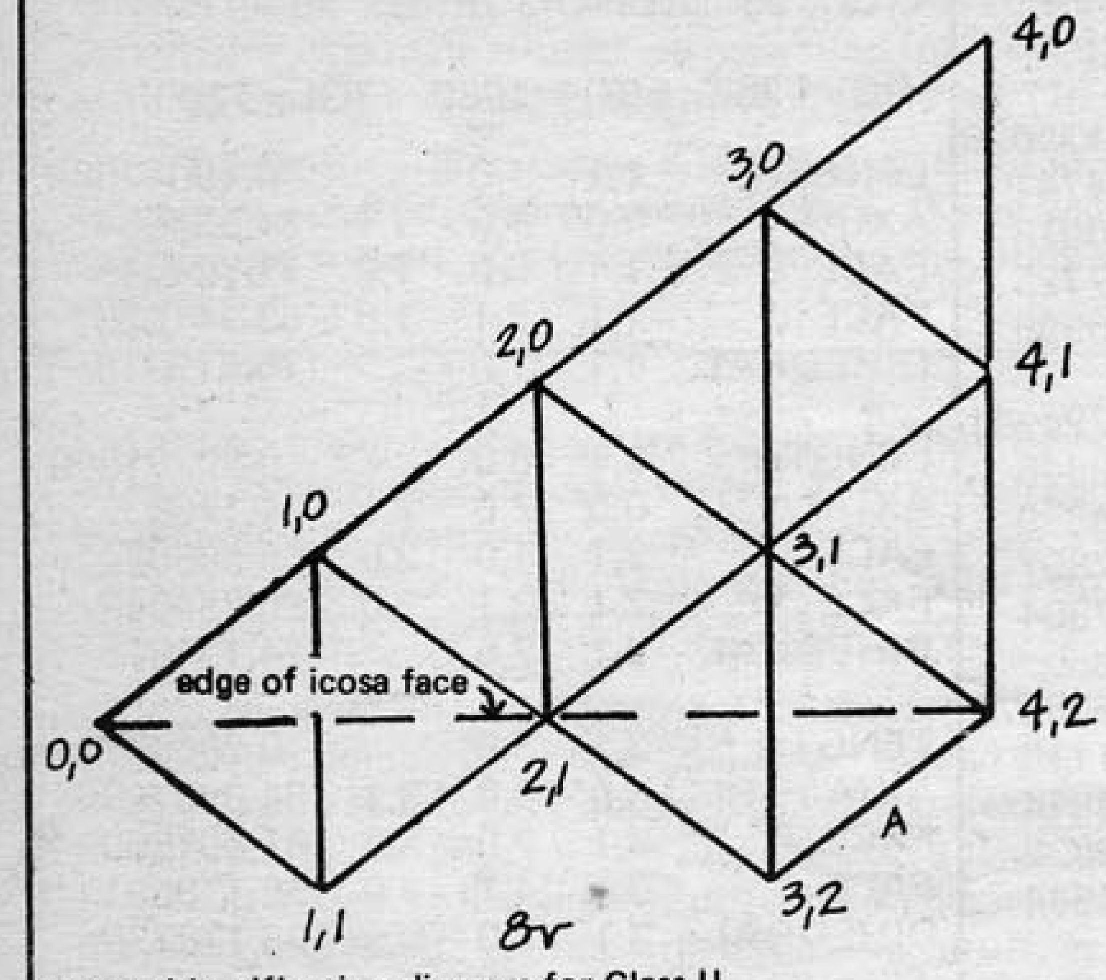
**On this page are Chord Factors for: class I (Alternate) method 1**

Below are chord factors for Class II, Method 3, what we call "triacon" in the rest of the book.

The figures are based on Class II geodesic spheres as developed by R. Buckminster Fuller. The numbers are from the computer readout generated by programs developed by Joseph D. Clinton under a NASA-sponsored research grant. "Advanced Structural Design Concepts for Future Space Missions," Final Report, March, 1970 NASA Contract NGR 14-008-002

*The general instructions on p. 108 apply to the below chord factors and angles, and to all the chord factors and angles in the book.*

The tables for Class II follow the same format as those for Class I except that the vertices are identified as in the diagram:




vertex identification diagram for Class II ("triacon") breakdown. From dotted line up is one of the 6 identical right triangles in the icosa face. Struts shown in this right triangle are repeated in the other five right triangles of the icosa face; see diagram right.

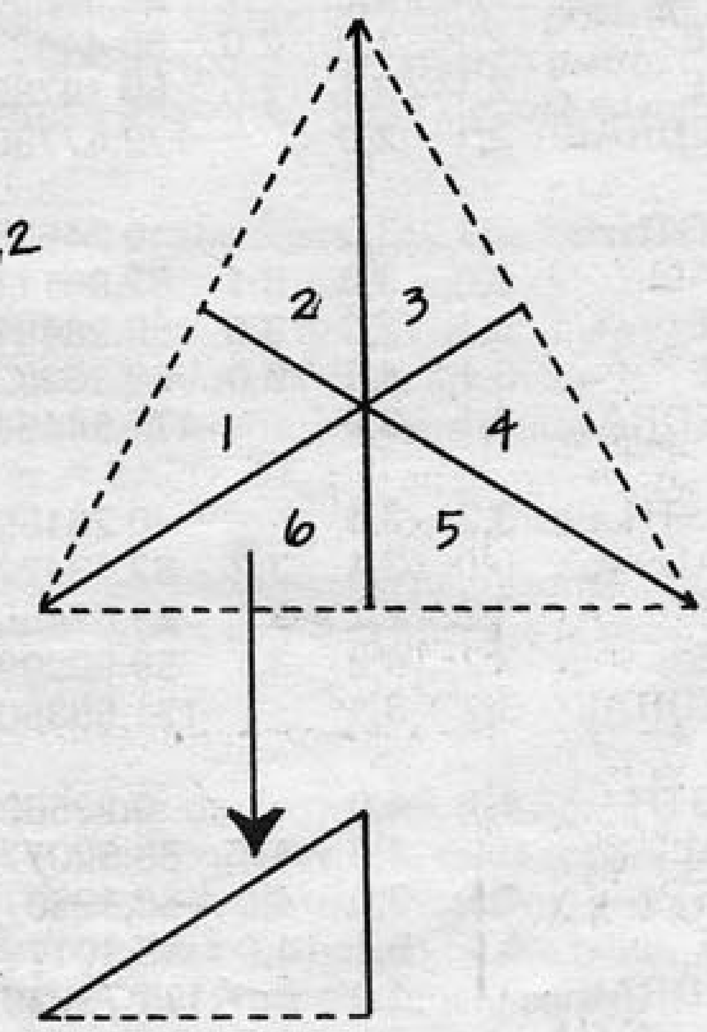
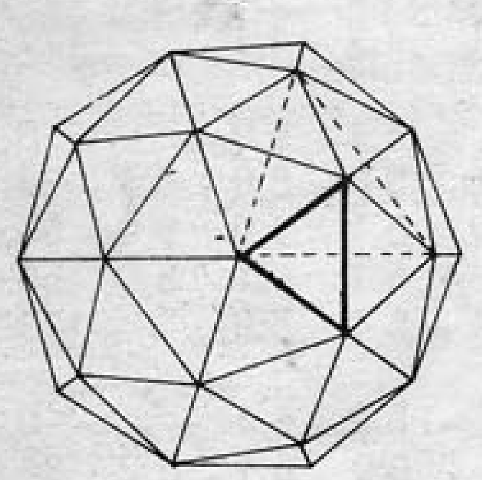
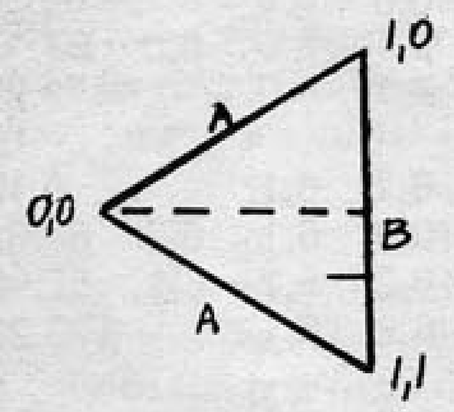



diagram above shows one of the 6 identical right triangles in the icosa face. Icosa face shown by dotted lines

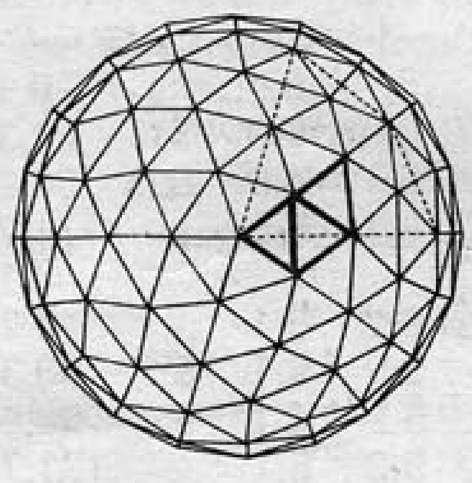


**2-FREQUENCY ICOSAHEDRON** class II method 3

| | | | | |
|---|---|---|---|---|
| LENGTH-A | 0,0 | 1,0 | | 0.640851 |
| LENGTH B | 1,1 | 1,0 | | 0.713644 |
| AXIAL | 0.0 | 1,0 | 0,0 | 71.31131 |
| AXIAL | 0.0 | 1,0 | 1,1 | 69.09484 |
| FACE | 1,1 | 0,0 | 1,0 | 67.66866 |
| FACE | 0,0 | 1,0 | 1,1 | 56.16566 |
| DIHEDRAL | 0,0 | 1,0 | | 153.78959 |
| DIHEDRAL | 1,1 | 1,0 | | 161.94600 |

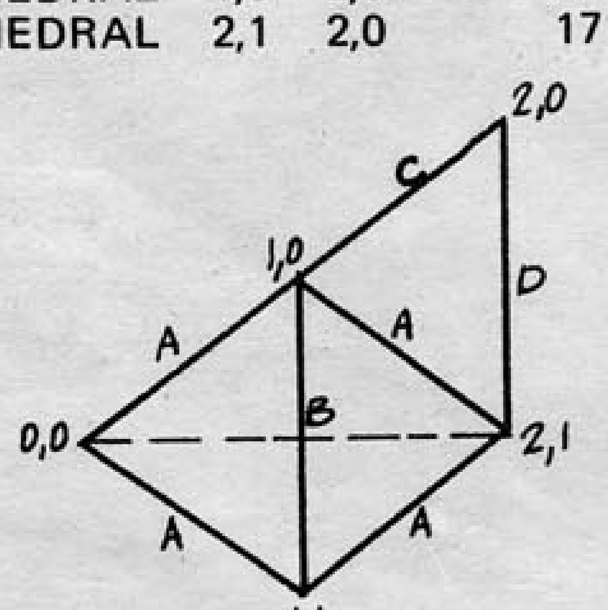



On this page are Chord Factors for: class II (Triacon) method 3

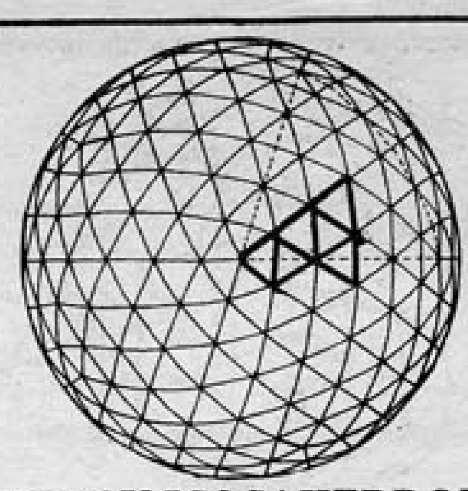


**4-FREQUENCY ICOSAHEDRON** class II method 3

| | | | | |
|---|---|---|---|---|
| LENGTH-A | 0,0 | 1,0 | | .33609 |
| LENGTH-B | 1,1 | 1,0 | | .38948 |
| LENGTH-A | 2,1 | 1,0 | | .33609 |
| LENGTH-C | 1,0 | 2,0 | | .31337 |
| LENGTH-D | 2,1 | 2,0 | | .36284 |
| AXIAL | 0.0 | 1,0 | 0,0 | 80.31740 |
| AXIAL | 0.0 | 1,0 | 1,1 | 78.77250 |
| AXIAL | 0.0 | 1,0 | 2,1 | 80.31740 |
| AXIAL | 0.0 | 2,0 | 1,0 | 80.98560 |
| AXIAL | 0.0 | 2,0 | 2,1 | 79.54750 |
| FACE | 1,1 | 0,0 | 1,0 | 70.81977 |
| FACE | 0,0 | 1,0 | 1,1 | 54.58971 |
| FACE | 1,1 | 1,0 | 2,1 | 54.58971 |
| FACE | 1,1 | 2,1 | 1,0 | 70.81977 |
| FACE | 1,0 | 2,1 | 2,0 | 53.10875 |
| FACE | 2,1 | 1,0 | 2,0 | 67.82582 |
| FACE | 1,0 | 2,0 | 2,1 | 59.06569 |
| DIHEDRAL | 0,0 | 1,0 | | 166.04826 |
| DIHEDRAL | 1,1 | 1,0 | | 172.07843 |
| DIHEDRAL | 2,1 | 1,0 | | 167.17545 |
| DIHEDRAL | 1,0 | 2,0 | | 166.30846 |
| DIHEDRAL | 2,1 | 2,0 | | 171.37576 |

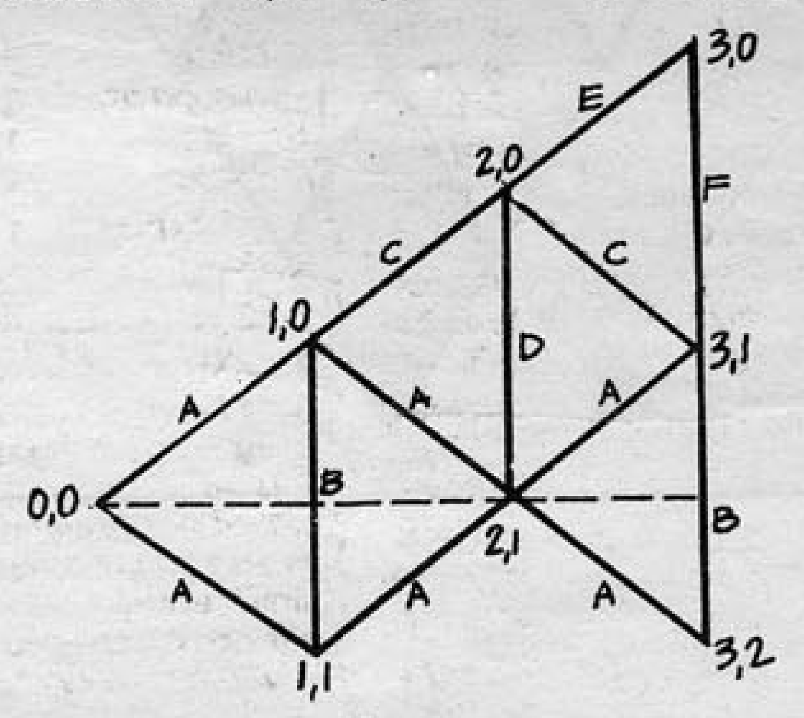


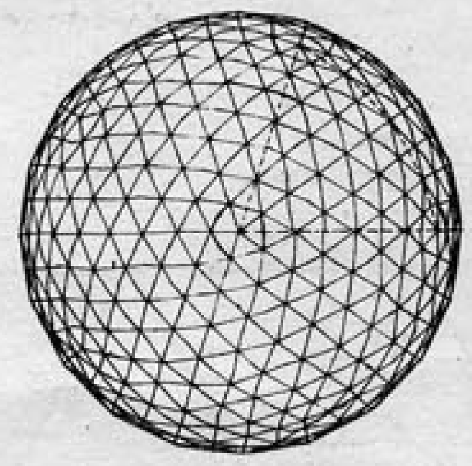

CHORD FACTORS and ANGLES



**6-FREQUENCY ICOSAHEDRON** class II method 3

| | | | | |
|---|---|---|---|---|
| LENGTH-A | 0,0 | 1,0 | | .22425 |
| LENGTH-A | 2,1 | 1,0 | | .22425 |
| LENGTH-A | 2,1 | 3,1 | | .22425 |
| LENGTH-B | 1,1 | 1,0 | | .26427 |
| LENGTH-B | 3,2 | 3,1 | | .26427 |
| LENGTH-C | 1,0 | 2,0 | | .21877 |
| LENGTH-C | 3,1 | 2,0 | | .21877 |
| LENGTH-D | 2,1 | 2,0 | | .25562 |
| LENGTH-E | 2,0 | 3,0 | | .20604 |
| LENGTH-F | 3,1 | 3,0 | | .23182 |
| AXIAL | 0.0 | 1,0 | 0,0 | 83.50440 |
| AXIAL | 0.0 | 1,0 | 1,1 | 82.40690 |
| AXIAL | 0.0 | 1,0 | 2,1 | 83.50440 |
| AXIAL | 0.0 | 2,0 | 1,0 | 83.72000 |
| AXIAL | 0.0 | 2,0 | 2,1 | 82.65690 |
| AXIAL | 0.0 | 2,0 | 3,1 | 83.72000 |
| AXIAL | 0.0 | 3,0 | 3,0 | 84.08690 |
| AXIAL | 0.0 | 3,0 | 3,1 | 83.01080 |
| AXIAL | 0.0 | 3,1 | 2,1 | 83.50440 |
| AXIAL | 0.0 | 3,1 | 3,2 | 82.40696 |
| FACE | 1,1 | 0,0 | 1,0 | 71.46610 |
| FACE | 0,0 | 1,0 | 1,1 | 54.26700 |
| FACE | 1,1 | 1,0 | 2,1 | 54.26700 |
| FACE | 1,1 | 2,1 | 1,0 | 71.46610 |
| FACE | 1,0 | 2,1 | 2,0 | 53.58140 |
| FACE | 2,1 | 1,0 | 2,0 | 70.09020 |
| FACE | 1,0 | 2,0 | 2,1 | 56.32840 |
| FACE | 2,1 | 2,0 | 3,1 | 56.32840 |
| FACE | 2,1 | 3,1 | 2,0 | 70.09020 |
| FACE | 2,0 | 2,1 | 3,1 | 53.58140 |
| FACE | 2,0 | 3,1 | 3,0 | 54.45830 |
| FACE | 3,1 | 2,0 | 3,0 | 66.09890 |
| FACE | 2,0 | 3,0 | 3,1 | 57.27480 |
| FACE | 3,2 | 2,1 | 3,1 | 71.46610 |
| FACE | 2,1 | 3,1 | 3,2 | 54.26700 |
| DIHEDRAL | 0,0 | 1,0 | | 170.60280 |
| DIHEDRAL | 1,1 | 1,0 | | 174.87730 |
| DIHEDRAL | 2,1 | 1,0 | | 170.90110 |
| DIHEDRAL | 1,0 | 2,0 | | 170.68770 |
| DIHEDRAL | 2,1 | 2,0 | | 174.65000 |
| DIHEDRAL | 3,1 | 2,0 | | 171.64300 |
| DIHEDRAL | 2,0 | 3,0 | | 171.47280 |
| DIHEDRAL | 3,1 | 3,0 | | 174.06170 |
| DIHEDRAL | 2,1 | 3,1 | | 171.64300 |
| DIHEDRAL | 3,2 | 3,1 | | 174.87730 |



**8-FREQUENCY ICOSAHEDRON** class II method 3

| | | | | |
|---|---|---|---|---|
| LENGTH | 0,0 | 1,0 | | 0.17026386 |
| LENGTH | 1,0 | 1,0 | | 0.19937078 |
| LENGTH | 1,0 | 2,0 | | 0.16701614 |
| LENGTH | 2,0 | 1,1 | | 0.19563944 |
| LENGTH | 2,0 | 3,0 | | 0.16103172 |
| LENGTH | 3,0 | 2,1 | | 0.18493544 |
| LENGTH | 3,0 | 4,0 | | 0.15533460 |
| LENGTH | 4,0 | 3,1 | | 0.16871032 |
| AXIAL | 0.0 | 0,0 | 1,0 | 85° 7′ 0″ |
| AXIAL | 0.0 | 1,0 | 1,0 | 84° 16′ 44″ |
| AXIAL | 0.0 | 1,0 | 2,0 | 85° 12′ 36″ |
| AXIAL | 0.0 | 2,0 | 1,1 | 84° 23′ 11″ |
| AXIAL | 0.0 | 2,0 | 3,0 | 85° 22′ 58″ |
| AXIAL | 0.0 | 3,0 | 2,1 | 84° 41′ 40″ |
| AXIAL | 0.0 | 3,0 | 4,0 | 85° 36′ 11″ |
| AXIAL | 0.0 | 4,0 | 3,1 | 85° 9′ 41″ |

We don't have face and dihedral angles for 8 frequency.

# COMPARE

The following comparison between Class I (Alternate) and Class II (Triacon) breakdown is reprinted from Edward Popko's *Geodesics.*

THE TRIACON BREAKDOWN

The triacon breakdown has these advantages over the other breakdowns

a. A minimum number of different components
b. A symmetry of relationship of adjacent faces making easy combination into diamonds.

and the following disadvantages:

a. A greater variation of member length than with the Alternate system.
b. No complete great circle delineated naturally by the structural pattern—such as the equatorial obtainable on the even number Alternate breakdowns. Consequently truncated base members must be used in every case.
c. Frequencies must always run in an even number—therefore there is less graduation in scale than is available with the Alternate breakdown.

In practice, the advantages of the Triacon become more emphatic in the higher frequencies—usually this means in the larger diameter structures such as those 100 feet or more...

THE ALTERNATE BREAKDOWN = CLASS I

The alternate breakdown has the following advantages:

a. A minimum variation in member length, and except for the pent joints, less variation in face angles.
b. In even frequencies, a continuous equator is delineated, so achieving hemispheres without the need for truncated members at the base.
c. As odd and even number frequencies are both both obtainable, a more gradual variation in scale of breakdown is available.

Disadvantages:

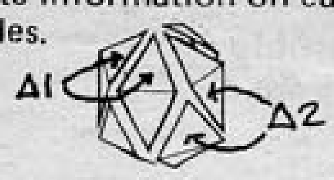
a. The number of different components in relation to frequency increase on a geometric scale...

continued from end of opposite page

| | | | |
|---|---|---|---|
| LENGTH-10 | 3,2 | 2,3 | .333333 |
| AXIAL | 2,3 | | 82.5461 |
| AXIAL | 3,2 | | 82.5461 |
| LENGTH-11 | 3,2 | 3,3 | .245992 |
| AXIAL | 3,3 | | 81.6616 |
| AXIAL | 3,2 | | 82.5381 |
| LENGTH-12 | 3,2 | 4,2 | .247825 |
| AXIAL | 4,2 | | 78.1855 |
| AXIAL | 3,2 | | 78 |
| AXIAL | 3,2 | | 79.9511 |
| TRIANGLE 2 | | | |
| LENGTH-13 | 4,1 | 3,1 | .246953 |
| AXIAL | 3,1 | | 74.9727 |
| AXIAL | 4,1 | | 77.1986 |
| LENGTH-14 | 3,1 | 2,1 | .224244 |
| AXIAL | 2,1 | | 73.3502 |
| AXIAL | 3,1 | | 73.4091 |
| LENGTH-15 | 2,1 | 1,1 | .190703 |
| AXIAL | 1,1 | | 79.2185 |
| AXIAL | 2,1 | | 77.8740 |
| LENGTH-16 | 4,1 | 3,2 | .329151 |
| AXIAL | 3,2 | | 79.8255 |
| AXIAL | 4,1 | | 80.7485 |
| LENGTH-17 | 3,1 | 3,2 | .339491 |
| AXIAL | 3,2 | | 79.7994 |
| AXIAL | 3,1 | | 79.1286 |
| LENGTH-18 | 3,1 | 2,2 | .331518 |
| AXIAL | 2,2 | | 78.5470 |
| AXIAL | 3,1 | | 78.8638 |
| LENGTH-19 | 2,1 | 2,2 | .329151 |
| AXIAL | 2,2 | | 78.8481 |
| AXIAL | 2,1 | | 79.1186 |
| LENGTH-20 | 2,1 | 1,2 | .303528 |
| AXIAL | 1,2 | | 80.3767 |
| AXIAL | 2,1 | | 79.7090 |
| LENGTH-21 | 3,2 | 2,3 | .303528 |
| AXIAL | 2,3 | | 79.7090 |
| AXIAL | 3,2 | | 80.3767 |
| LENGTH-23 | 3,2 | 2,2 | .226708 |
| AXIAL | 2,2 | | 73.6916 |
| AXIAL | 3,2 | | 75.1394 |
| LENGTH-22 | 3,2 | 3,3 | .276229 |
| AXIAL | 3,3 | | 82.5798 |
| AXIAL | 3,2 | | 82.2006 |

# ELLIPTICAL DOMES

There are 2 different basic triangles in the elliptical icosahedron and any breakdown will result in a different strut length in these two triangles. The tables contain separate information on each of these triangles.




The *expansion* refers to the amount of distortion along the zenith-to-zenith pole (an expansion of 1 being a sphere, greater than 1 a stretched dome, and less than 1 a squashed).

Keep in mind that the chords to the left of the line of symmetry, fig. (1), are the same as the ones to the right and that the 2 basic triangles share certain chords in the last row. Length data can be used in the same way as on p. 108; the axial angles may be different at each end of the strut so the coordinate names which end of the strut the angle refers to. In construction the axial angles can be rounded off a degree or two for convenience. I am not publishing dihedral angles because they are rarely used (except in sun dome type construction) and would take up a lot of space. The face angles can be calculated using the law of cosines. If you need the dihedral angles, some special expansion, or frequency, write and I'll send them for computer costs.

## ALTERNATE ELLIPTICAL

The vertices are labeled the same way as with the spherical, starting with 0,0 at each end of the two basic triangles.

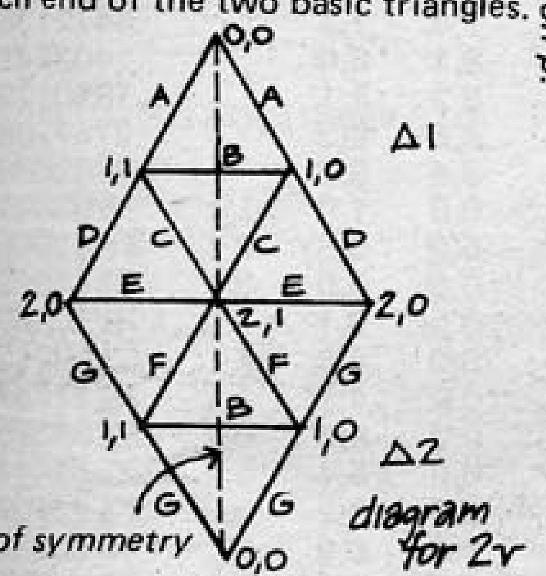
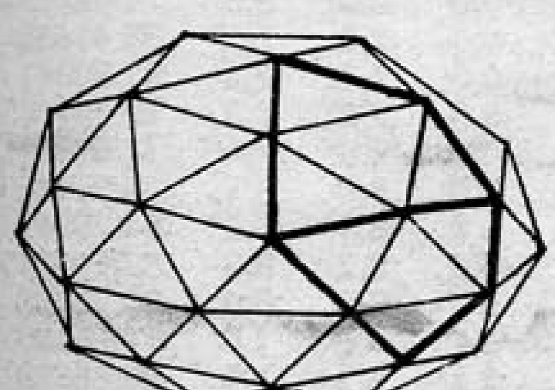



fig. 1

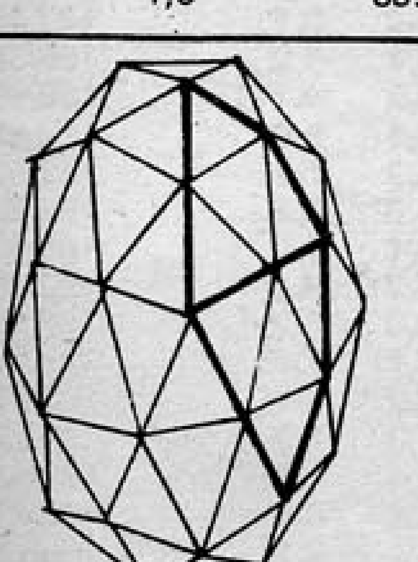
Note: There is a paper model of this on p.



ALTERNATE BREAKDOWN
FREQUENCY = 2 ZAFU
EXPANSION = 0.61800

TRIANGLE 1

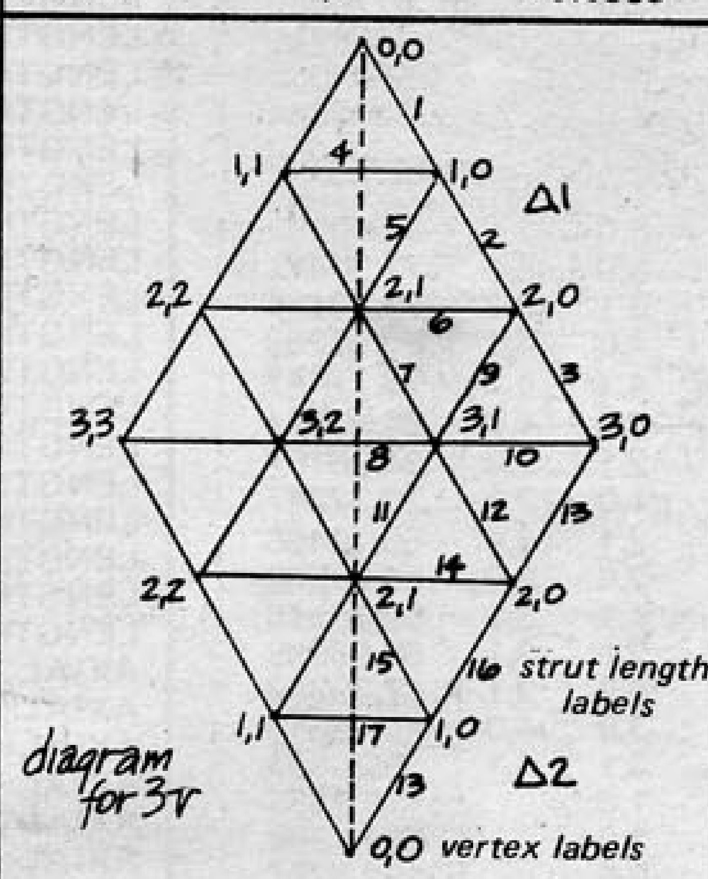
| | | | |
|---|---|---|---|
| LENGTH-A | 1,0 | 0,0 | .533771 |
| AXIAL | 0,0 | | 80.0425 |
| AXIAL | 1,0 | | 79.0533 |
| LENGTH-B | 1,1 | 1,0 | .618033 |
| AXIAL | 1,0 | | 77.8937 |
| AXIAL | 1,1 | | 77.8937 |
| LENGTH-C | 2,1 | 1,0 | .562773 |
| AXIAL | 1,0 | | 76.6841 |
| AXIAL | 2,1 | | 73.6152 |
| LENGTH-D | 2,0 | 1,0 | .445083 |
| AXIAL | 1,0 | | 76.8362 |
| AXIAL | 2,0 | | 73.0428 |
| LENGTH-E | 2,1 | 2,0 | .543035 |
| AXIAL | 2,1 | | 76.1696 |
| AXIAL | 2,1 | | 76.7847 |
| TRIANGLE 2 | | | |
| LENGTH-B | 1,1 | 1,0 | .618033 |
| AXIAL | 1,0 | | 72.0000 |
| AXIAL | 1,1 | | 72.0000 |
| LENGTH-F | 2,1 | 1,0 | .459493 |
| AXIAL | 1,0 | | 65.4404 |
| AXIAL | 2,1 | | 69.7881 |
| LENGTH-G | 2,0 | 1,0 | .418429 |
| AXIAL | 1,0 | | 69.0883 |
| AXIAL | 2,0 | | 71.9665 |
| LENGTH-G | 1,0 | 0,0 | .418429 |
| AXIAL | 0,0 | | 71.9265 |
| AXIAL | 1,0 | | 69.0883 |

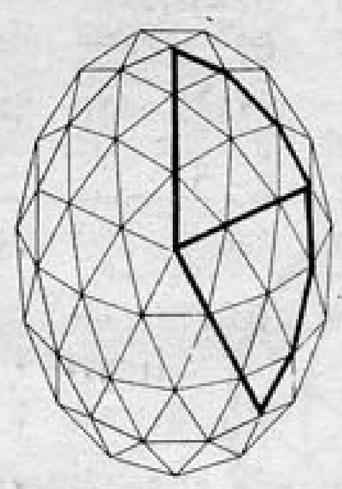


ALTERNATE BREAKDOWN
FREQUENCY = 2 EGG
EXPANSION - 1.61800

TRIANGLE 1

| | | | |
|---|---|---|---|
| LENGTH-A | 1,0 | 0,0 | .578607 |
| AXIAL | 0,0 | | 65.3146 |
| AXIAL | 1,0 | | 69.6860 |
| LENGTH-B | 1,1 | 1,0 | .618033 |
| AXIAL | 1,0 | | 65.4414 |
| AXIAL | 1,1 | | 65.4414 |
| LENGTH-C | 2,1 | 1,0 | .743487 |
| AXIAL | 1,0 | | 69.7882 |
| AXIAL | 2,1 | | 73.6147 |
| LENGTH-D | 2,0 | 1,0 | .749689 |
| AXIAL | 1,0 | | 74.4582 |
| AXIAL | 2,0 | | 77.7135 |
| LENGTH-E | 2,1 | 2,0 | .555583 |
| AXIAL | 2,0 | | 73.3128 |
| AXIAL | 2,1 | | 72.8299 |
| TRIANGLE 2 | | | |
| LENGTH-B | 1,1 | 1,0 | .618033 |
| AXIAL | 1,0 | | 72.0000 |
| AXIAL | 1,1 | | 72.0000 |
| LENGTH-F | 2,1 | 1,0 | .910576 |
| AXIAL | 1,0 | | 77.8929 |
| AXIAL | 2,1 | | 76.6834 |
| LENGTH-G | 2,0 | 1,0 | .788849 |
| AXIAL | 1,0 | | 79.0865 |
| AXIAL | 2,0 | | 78.3322 |
| LENGTH-G | 1,0 | 0,0 | .788849 |
| AXIAL | 0,0 | | 78.3322 |
| AXIAL | 1,0 | | 79.0865 |

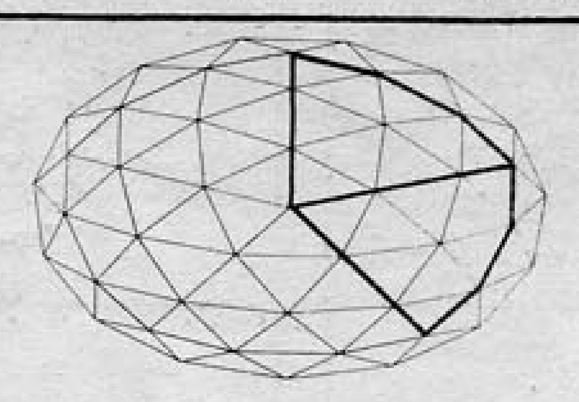


ALTERNATE BREAKDOWN
FREQUENCY = 3 EGG
EXPANSION = 1.61800

TRIANGLE 1

| | | | |
|---|---|---|---|
| LENGTH-1 | 1,0 | 0,0 | .357081 |
| AXIAL | 0,0 | | 74.0175 |
| AXIAL | 1,0 | | 75.3841 |
| LENGTH-2 | 2,0 | 1,0 | .485463 |
| AXIAL | 1,0 | | 75.5989 |
| AXIAL | 2,0 | | 78.2050 |
| LENGTH-3 | 3,0 | 2,0 | .498249 |
| AXIAL | 2,0 | | 81.4523 |
| AXIAL | 3,0 | | 82.5144 |
| LENGTH-4 | 1,1 | 1,0 | .403548 |
| AXIAL | 1,0 | | 72.5908 |
| AXIAL | 1,1 | | 72.5908 |
| LENGTH-5 | 2,1 | 1,0 | .451555 |
| AXIAL | 1,0 | | 73.7840 |
| AXIAL | 2,1 | | 76.0435 |
| LENGTH-6 | 2,1 | 2,0 | .421274 |
| AXIAL | 2,0 | | 75.7580 |
| AXIAL | 2,1 | | 75.0177 |
| LENGTH-7 | 3,1 | 2,1 | .544692 |
| AXIAL | 2,1 | | 78.4663 |
| AXIAL | 3,1 | | 80.1690 |
| LENGTH-8 | 3,2 | 3,1 | .403547 |
| AXIAL | 3,1 | | 77.2521 |
| AXIAL | 3,2 | | 77.2521 |
| LENGTH-9 | 3,1 | 2,0 | .485463 |
| AXIAL | 2,0 | | 78.2050 |
| AXIAL | 2,1 | | 79.4305 |
| LENGTH-10 | 3,1 | 3,0 | .359094 |
| AXIAL | 3,0 | | 79.5859 |
| AXIAL | 2,1 | | 79.3353 |
| TRIANGLE 2 | | | |
| LENGTH-11 | 3,1 | 2,1 | .586029 |
| AXIAL | 2,1 | | 81.5631 |
| AXIAL | 3,1 | | 80.8686 |
| LENGTH-12 | 3,1 | 2,0 | .594565 |
| AXIAL | 2,0 | | 82.0554 |
| AXIAL | 3,1 | | 81.3864 |
| LENGTH-13 | 1,0 | 0,0 | .494368 |
| AXIAL | 0,0 | | 82.4553 |
| AXIAL | 1,0 | | 82.8739 |
| LENGTH-13 | 3,0 | 2,0 | .494368 |
| AXIAL | 2,0 | | 82.8739 |
| AXIAL | 3,0 | | 82.4553 |
| LENGTH-14 | 2,1 | 2,0 | .412910 |
| AXIAL | 2,0 | | 78.0031 |
| AXIAL | 2,1 | | 77.9811 |
| LENGTH-15 | 2,1 | 1,1 | .615526 |
| AXIAL | 1,0 | | 81.9847 |
| AXIAL | 2,1 | | 81.9701 |
| LENGTH-16 | 2,0 | 1,0 | .594565 |
| AXIAL | 1,0 | | 82.0554 |
| AXIAL | 2,0 | | 82.0554 |
| LENGTH-17 | 1,0 | 1,0 | .403548 |
| AXIAL | 1,0 | | 78.2503 |
| AXIAL | 1,1 | | 78.2503 |



ALTERNATE BREAKDOWN
FREQUENCY = 3 ZAFU
EXPANSION = 0.61800

TRIANGLE 1

| | | | |
|---|---|---|---|
| LENGTH-1 | 1,0 | 0,0 | .345326 |
| AXIAL | 0,0 | | 83.7568 |
| AXIAL | 1,0 | | 83.5152 |
| LENGTH-2 | 2,0 | 1,0 | .367465 |
| AXIAL | 1,0 | | 81.8237 |
| AXIAL | 2,0 | | 80.6379 |
| LENGTH-3 | 3,0 | 2,0 | .270413 |
| AXIAL | 2,0 | | 80.5045 |
| AXIAL | 3,0 | | 78.7365 |
| LENGTH-4 | 1,1 | 1,0 | .403548 |
| AXIAL | 1,0 | | 82.5592 |
| AXIAL | 1,1 | | 82.5592 |
| LENGTH-5 | 2,1 | 1,0 | .396438 |
| AXIAL | 1,0 | | 82.0864 |
| AXIAL | 2,1 | | 81.3232 |
| LENGTH-6 | 2,1 | 2,0 | .408974 |
| AXIAL | 2,0 | | 81.2193 |
| AXIAL | 2,1 | | 81.5911 |
| LENGTH-7 | 3,1 | 2,1 | .348879 |
| AXIAL | 2,1 | | 80.1293 |
| AXIAL | 2,1 | | 78.2346 |
| LENGTH-8 | 3,2 | 3,1 | .403547 |
| AXIAL | 3,1 | | 80.2827 |
| AXIAL | 3,2 | | 80.2827 |
| LENGTH-9 | 3,1 | 2,0 | .367465 |
| AXIAL | 2,0 | | 80.6379 |
| AXIAL | 3,1 | | 79.3178 |
| LENGTH-10 | 3,1 | 3,0 | .344527 |
| AXIAL | 3,0 | | 81.1816 |
| AXIAL | 3,1 | | 81.5156 |
| TRIANGLE 2 | | | |
| LENGTH-11 | 3,1 | 2,1 | .322275 |
| AXIAL | 2,1 | | 75.1273 |
| AXIAL | 3,1 | | 77.2476 |
| LENGTH-12 | 3,1 | 2,0 | .300028 |
| AXIAL | 2,0 | | 74.6243 |
| AXIAL | 3,1 | | 76.8781 |
| LENGTH-13 | 3,0 | 2,0 | .273121 |
| AXIAL | 2,0 | | 77.4455 |
| AXIAL | 3,0 | | 78.8497 |
| LENGTH-14 | 2,1 | 2,0 | .412220 |
| AXIAL | 2,0 | | 78.3722 |
| AXIAL | 2,1 | | 78.4240 |
| LENGTH-15 | 2,1 | 1,0 | .300536 |
| AXIAL | 1,0 | | 73.9513 |
| AXIAL | 2,1 | | 74.0238 |
| LENGTH-16 | 2,0 | 1,0 | .300028 |
| AXIAL | 1,0 | | 74.6243 |
| AXIAL | 2,0 | | 74.6243 |
| LENGTH-17 | 1,1 | 1,0 | .403548 |
| AXIAL | 1,0 | | 78.6308 |
| AXIAL | 1,1 | | 78.6308 |

## TRIACON ELLIPTICAL

This diagram (fig. 2) demonstrates the congruent triangles and struts in a 2v. The same symmetries hold for the 4v with the additional fact that for the triangle 1's the edge of the icosa (dotted lines) is also a line of symmetry and the struts repeated on both sides of it will be the same.

The vertices in the 2 basic triangles are labeled like this for triacon:

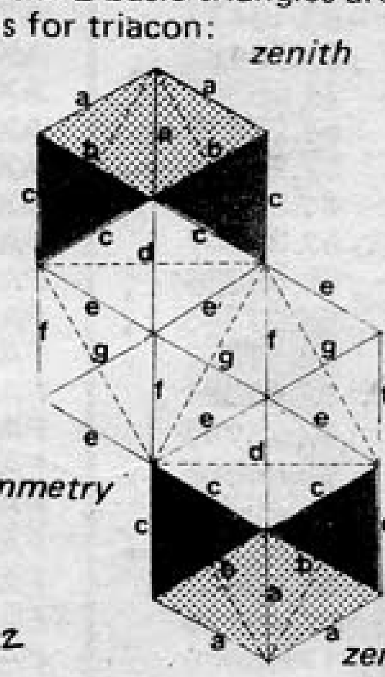
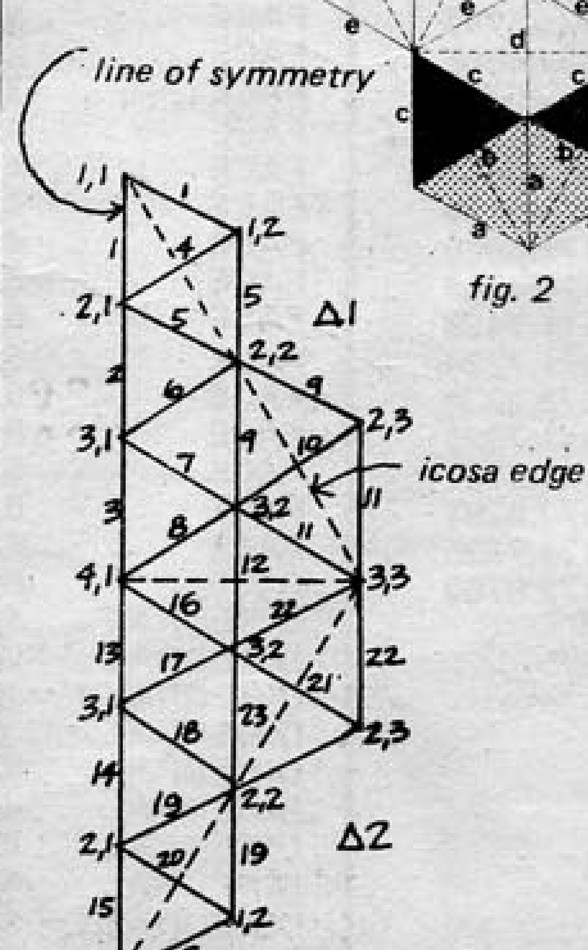


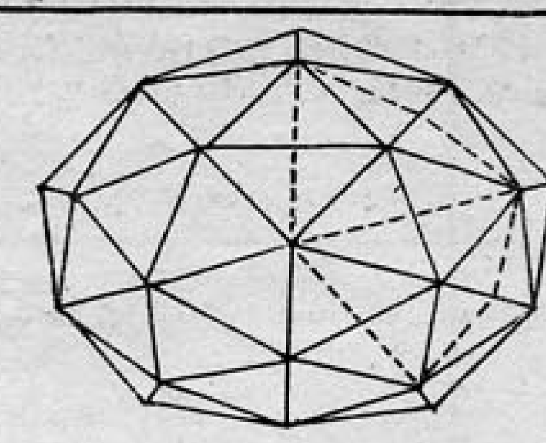

fig. 2




strut length labels and vertex labels for a 4v Triacon.

fig. 3

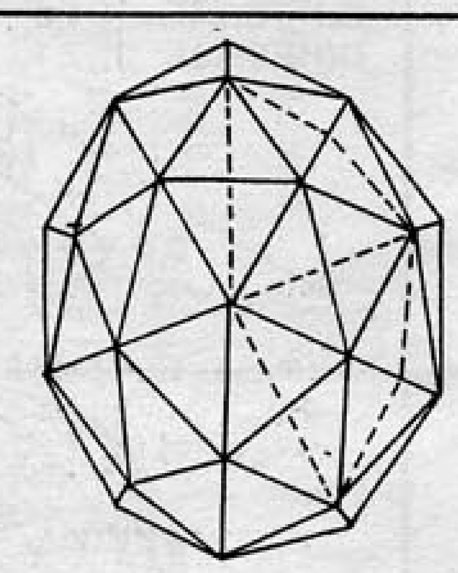
For the strut length label for 2v see fig. (2) and for vertex labels use up to 2,2 on fig. (3). There is a paper model of the 2v expansion 0.618 on p. 124.



TRIACON BREAKDOWN
FREQUENCY = 2 ZAFU
EXPANSION = 0.61800

TRIANGLE 1

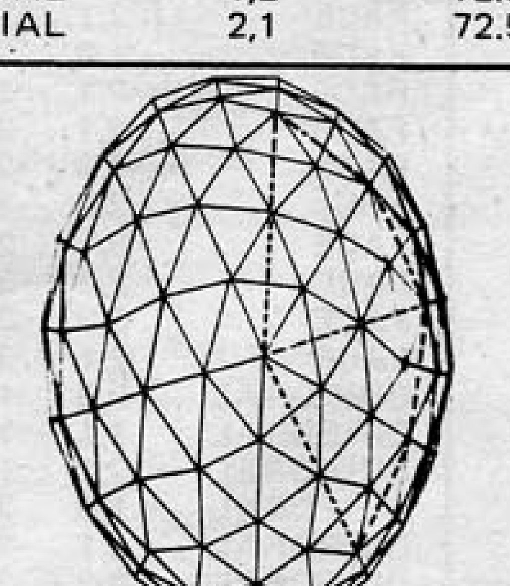
| | | | |
|---|---|---|---|
| LENGTH-A | 2,1 | 1,1 | .620184 |
| AXIAL | 1,1 | | 78.1926 |
| AXIAL | 2,1 | | 76.5349 |
| LENGTH-B | 2,1 | 1,2 | .713643 |
| AXIAL | 1,2 | | 75.4669 |
| AXIAL | 2,1 | | 75.4669 |
| LENGTH-C | 2,1 | 2,2 | .579723 |
| AXIAL | 2,2 | | 72.0687 |
| AXIAL | 2,1 | | 75.5755 |
| LENGTH-D | 2,1 | 3,1 | .530577 |
| AXIAL | 3,1 | | 62.1713 |
| AXIAL | 2,1 | | 70.2740 |
| TRIANGLE 2 | | | |
| LENGTH-E | 2,1 | 2,2 | .607478 |
| AXIAL | 2,2 | | 72.9138 |
| AXIAL | 2,1 | | 70.8042 |
| LENGTH-F | 2,1 | 1,1 | .402019 |
| AXIAL | 1,1 | | 63.6428 |
| AXIAL | 2,1 | | 60.2092 |
| LENGTH-G | 2,1 | 1,2 | .649834 |
| AXIAL | 1,2 | | 67.5946 |
| AXIAL | 2,1 | | 67.5946 |



TRIACON BREAKDOWN
FREQUENCY = 2 EGG
EXPANSION = 1.61800

TRIANGLE 1

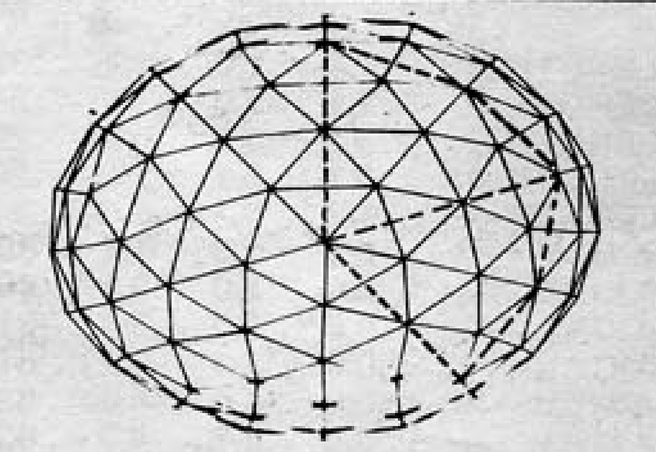
| | | | |
|---|---|---|---|
| LENGTH-A | 2,1 | 1,1 | .692035 |
| AXIAL | 1,1 | | 61.3078 |
| AXIAL | 2,1 | | 67.6662 |
| LENGTH-B | 2,1 | 1,2 | .713643 |
| AXIAL | 1,2 | | 62.8087 |
| AXIAL | 2,1 | | 62.8087 |
| LENGTH-C | 2,1 | 2,2 | .778458 |
| AXIAL | 2,2 | | 73.6339 |
| AXIAL | 2,1 | | 70.2562 |
| LENGTH-D | 2,1 | 3,1 | 1.05144 |
| AXIAL | 3,1 | | 75.8262 |
| AXIAL | 2,1 | | 71.9315 |
| TRIANGLE 2 | | | |
| LENGTH-E | 2,1 | 2,2 | .720932 |
| AXIAL | 2,2 | | 72.2865 |
| AXIAL | 2,1 | | 73.2628 |
| LENGTH-F | 2,1 | 1,1 | 1.03086 |
| AXIAL | 1,1 | | 77.7145 |
| AXIAL | 2,1 | | 78.3811 |
| LENGTH-F | 2,1 | 1,1 | 1.03086 |
| AXIAL | 1,1 | | 77.7145 |
| AXIAL | 2,1 | | 78.3811 |
| LENGTH-G | 2,1 | 1,2 | .858506 |
| AXIAL | 1,2 | | 72.5488 |
| AXIAL | 2,1 | | 72.5488 |



TRIACON BREAKDOWN
FREQUENCY = 4 EGG
EXPANSION 1.61800

TRIANGLE 1

| | | | |
|---|---|---|---|
| LENGTH-1 | 2,1 | 1,1 | .291222 |
| AXIAL | 1,1 | | 76.8189 |
| AXIAL | 2,1 | | 77.6136 |
| LENGTH-2 | 3,1 | 2,1 | .418726 |
| AXIAL | 2,1 | | 76.1561 |
| AXIAL | 3,1 | | 78.3853 |
| LENGTH-3 | 4,1 | 3,1 | .498661 |
| AXIAL | 3,1 | | 80.2670 |
| AXIAL | 4,1 | | 81.6644 |
| LENGTH-4 | 2,1 | 1,2 | .333333 |
| AXIAL | 1,2 | | 75.3051 |
| AXIAL | 2,1 | | 75.3051 |
| LENGTH-5 | 2,1 | 2,2 | .382492 |
| AXIAL | 2,2 | | 77.0644 |
| AXIAL | 2,1 | | 75.3257 |
| LENGTH-6 | 3,1 | 2,2 | .369767 |
| AXIAL | 2,2 | | 76.1465 |
| AXIAL | 3,1 | | 76.8214 |
| LENGTH-7 | 3,1 | 3,2 | .416405 |
| AXIAL | 3,2 | | 79.4932 |
| AXIAL | 3,1 | | 78.3196 |
| LENGTH-8 | 4,1 | 3,2 | .382492 |
| AXIAL | 3,2 | | 78.9312 |
| AXIAL | 4,1 | | 79.4683 |
| LENGTH-9 | 3,2 | 2,2 | .450817 |
| AXIAL | 2,2 | | 79.0514 |
| AXIAL | 3,2 | | 80.6253 |
| LENGTH-10 | 3,2 | 2,3 | .333333 |
| AXIAL | 2,3 | | 78.9158 |
| AXIAL | 3,2 | | 78.9158 |
| LENGTH-11 | 3,2 | 3,3 | .372230 |
| AXIAL | 3,3 | | 83.2359 |
| AXIAL | 3,2 | | 82.6929 |
| LENGTH-12 | 3,2 | 4,2 | .491114 |
| AXIAL | 4,2 | | 83.2419 |
| AXIAL | 3,2 | | 82.5023 |
| TRIANGLE 2 | | | |
| LENGTH-13 | 4,1 | 3,1 | .562712 |
| AXIAL | 3,1 | | 83.2072 |
| AXIAL | 4,1 | | 82.6188 |
| LENGTH-14 | 3,1 | 2,1 | .587072 |
| AXIAL | 2,1 | | 83.4997 |
| AXIAL | 3,1 | | 83.4904 |
| LENGTH-15 | 2,1 | 1,1 | .449176 |
| AXIAL | 1,1 | | 84.3987 |
| AXIAL | 2,1 | | 84.7067 |
| LENGTH-16 | 4,1 | 3,2 | .420724 |
| AXIAL | 3,2 | | 80.9436 |
| AXIAL | 4,1 | | 80.4348 |
| LENGTH-17 | 3,1 | 3,2 | .417835 |
| AXIAL | 3,2 | | 80.5673 |
| AXIAL | 3,1 | | 80.8345 |
| LENGTH-18 | 3,1 | 2,2 | .434271 |
| AXIAL | 2,2 | | 81.2813 |
| AXIAL | 3,1 | | 81.1842 |
| LENGTH-19 | 2,1 | 2,2 | .420724 |
| AXIAL | 2,2 | | 81.2969 |
| AXIAL | 2,1 | | 81.2125 |
| LENGTH-20 | 2,1 | 1,2 | .400996 |
| AXIAL | 1,2 | | 81.7135 |
| AXIAL | 2,1 | | 81.9592 |
| LENGTH-21 | 3,2 | 2,3 | .400996 |
| AXIAL | 2,3 | | 81.9592 |
| AXIAL | 3,2 | | 81.7135 |
| LENGTH-22 | 3,2 | 3,3 | .311805 |
| AXIAL | 3,3 | | 81.9171 |
| AXIAL | 3,2 | | 82.1298 |
| LENGTH-23 | 3,2 | 2,2 | .571025 |
| AXIAL | 2,2 | | 83.5990 |
| AXIAL | 3,2 | | 83.3401 |



TRIACON BREAKDOWN
FREQUENCY = 4 ZAFU
EXPANSION = 0.61800

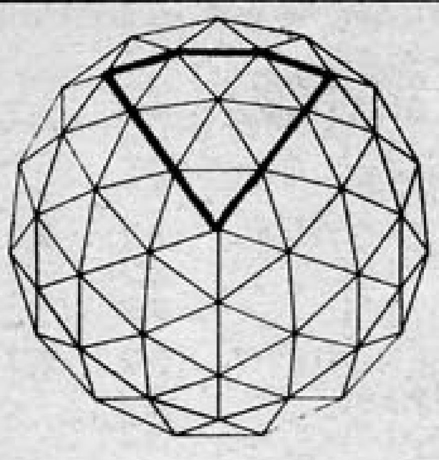
TRIANGLE 1

| | | | |
|---|---|---|---|
| LENGTH-1 | 2,1 | 1,1 | .284682 |
| AXIAL | 1,1 | | 84.8883 |
| AXIAL | 2,1 | | 84.7560 |
| LENGTH-2 | 3,1 | 2,1 | .339072 |
| AXIAL | 2,1 | | 82.9303 |
| AXIAL | 3,1 | | 82.1528 |
| LENGTH-3 | 4,1 | 3,1 | .294883 |
| AXIAL | 3,1 | | 80.9677 |
| AXIAL | 4,1 | | 79.3063 |
| LENGTH-4 | 2,1 | 1,2 | .333333 |
| AXIAL | 1,2 | | 83.9348 |
| AXIAL | 2,1 | | 83.9348 |
| LENGTH-5 | 2,1 | 2,2 | .346513 |
| AXIAL | 2,2 | | 82.8373 |
| AXIAL | 2,1 | | 83.3116 |
| LENGTH-6 | 3,1 | 2,2 | .360162 |
| AXIAL | 2,2 | | 82.8744 |
| AXIAL | 3,1 | | 82.6149 |
| LENGTH-7 | 3,1 | 3,2 | .340161 |
| AXIAL | 3,2 | | 81.3366 |
| AXIAL | 3,1 | | 82.1781 |
| LENGTH-8 | 4,1 | 3,2 | .346513 |
| AXIAL | 3,2 | | 81.7785 |
| AXIAL | 4,1 | | 81.2158 |
| LENGTH-9 | 3,2 | 2,2 | .313561 |
| AXIAL | 2,2 | | 82.0800 |
| AXIAL | 3,2 | | 80.9075 |

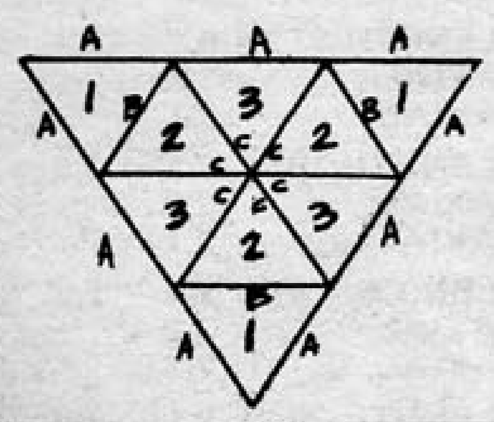
*continued on opposite page*

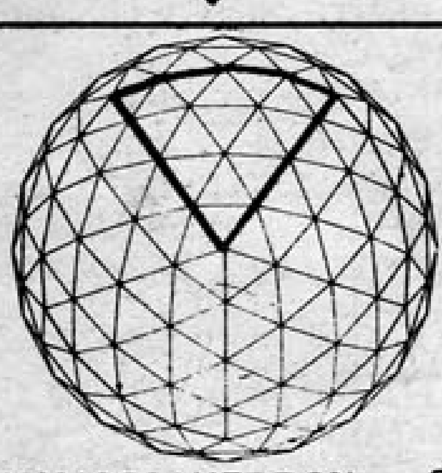
**On this page are Chord Factors for: Elliptical Domes**

Figures given below are for Class I (Alternate), Method 2. Edges of the icosa face are divided into equal parts, the triangles are more equilateral, the dome is structurally stronger, but you do not get the smooth arcs of Method 1. Make models of a given frequency in both methods to see the differences. We have not built any domes with this method.

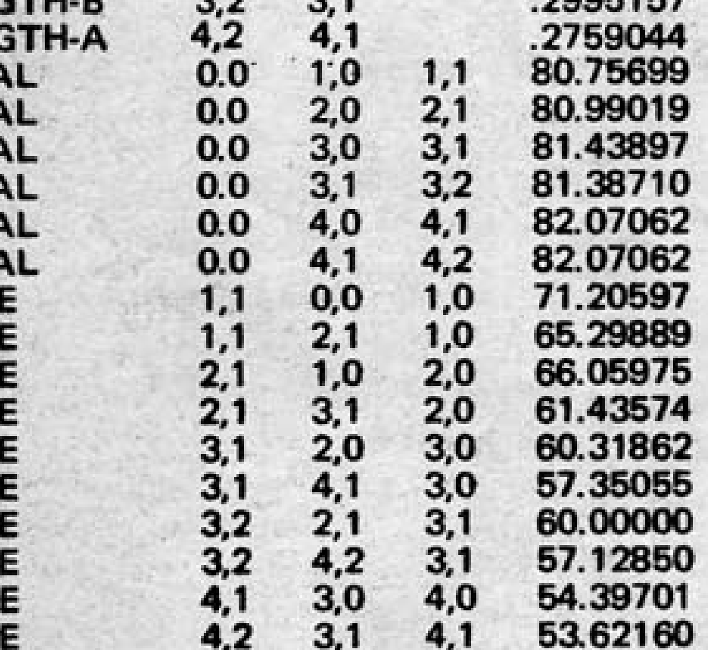


| 3-FREQUENCY ICOSAHEDRON | | | | CLASS I METHOD 2 |
|---|---|---|---|---|
| LENGTH-B | 1,1 | 1,0 | | 0.4240625 |
| LENGTH-C | 2,1 | 2,0 | | 0.4041944 |
| LENGTH-A | 3,1 | 3,0 | | 0.3669588 |
| LENGTH-A | 3,2 | 3,1 | | 0.3669588 |
| AXIAL | 0.0 | 1,0 | 1,1 | 77.75857 |
| AXIAL | 0.0 | 2,0 | 2,1 | 78.34037 |
| AXIAL | 0.0 | 3,0 | 3,1 | 79.42750 |
| AXIAL | 0.0 | 3,1 | 3,2 | 79.42150 |
| FACE | 1,1 | 0,0 | 1,0 | 70.59285 |
| FACE | 1,1 | 2,1 | 1,0 | 63.27959 |
| FACE | 2,1 | 1,0 | 2,0 | 63.00334 |
| FACE | 2,1 | 3,1 | 2,0 | 58.36019 |
| FACE | 3,1 | 2,0 | 3,0 | 54.70356 |
| FACE | 3,2 | 2,1 | 3,1 | 53.99331 |
| DIHEDRAL | 1,1 | 1,0 | | 169.34601 |
| DIHEDRAL | 2,1 | 2,0 | | 166.66061 |
| DIHEDRAL | 3,l | 3,0 | | 164.81383 |
| DIHEDRAL | 3,2 | 3,1 | | 164.40862 |





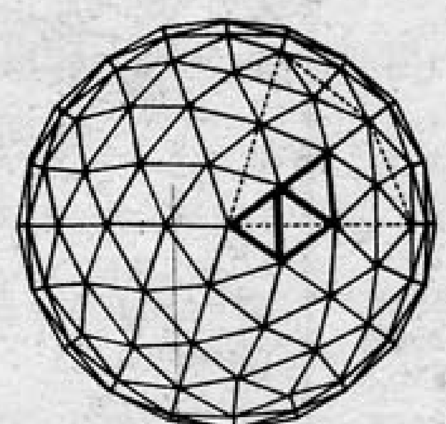
| 4-FREQUENCY ICOSAHEDRON | | | | CLASS I METHOD 2 |
|---|---|---|---|---|
| LENGTH-E | 1,1 | 1,0 | | .3212440 |
| LENGTH-C | 2,1 | 2,0 | | .3132066 |
| LENGTH-D | 3,1 | 3,0 | | .2977251 |
| LENGTH-B | 3,2 | 3,1 | | .2995157 |
| LENGTH-A | 4,2 | 4,1 | | .2759044 |
| AXIAL | 0.0 | 1,0 | 1,1 | 80.75699 |
| AXIAL | 0.0 | 2,0 | 2,1 | 80.99019 |
| AXIAL | 0.0 | 3,0 | 3,1 | 81.43897 |
| AXIAL | 0.0 | 3,1 | 3,2 | 81.38710 |
| AXIAL | 0.0 | 4,0 | 4,1 | 82.07062 |
| AXIAL | 0.0 | 4,1 | 4,2 | 82.07062 |
| FACE | 1,1 | 0,0 | 1,0 | 71.20597 |
| FACE | 1,1 | 2,1 | 1,0 | 65.29889 |
| FACE | 2,1 | 1,0 | 2,0 | 66.05975 |
| FACE | 2,1 | 3,1 | 2,0 | 61.43574 |
| FACE | 3,1 | 2,0 | 3,0 | 60.31862 |
| FACE | 3,1 | 4,1 | 3,0 | 57.35055 |
| FACE | 3,2 | 2,1 | 3,1 | 60.00000 |
| FACE | 3,2 | 4,2 | 3,1 | 57.12850 |
| FACE | 4,1 | 3,0 | 4,0 | 54.39701 |
| FACE | 4,2 | 3,1 | 4,1 | 53.62160 |
| DIHEDRAL | 1,1 | 1,0 | | 172.5324 |
| DIHEDRAL | 2,1 | 2,0 | | 171.0111 |
| DIHEDRAL | 3,1 | 3,0 | | 169.5426 |
| DIHEDRAL | 3,2 | 3,1 | | 169.3659 |
| DIHEDRAL | 4,1 | 4,0 | | 168.5529 |
| DIHEDRAL | 4,2 | 4,1 | | 168.2212 |



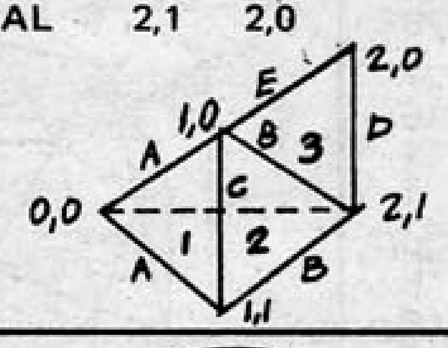
**On this page are Chord Factors for: various other methods and breakdowns**

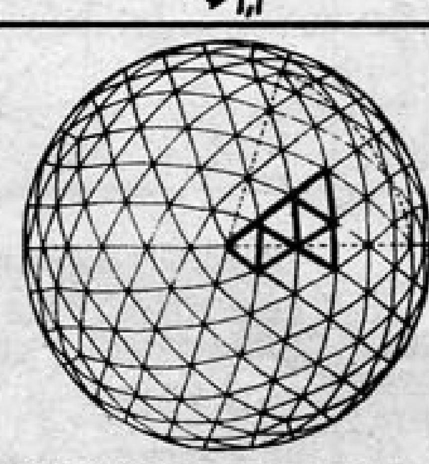
CHORD FACTORS and ANGLES

Figures below are for Class II (Triacon), Method 1. This method will probably produce smoother arcs than the triacon chord factors we have used, as shown on p. 110. We have not built any domes with this method.

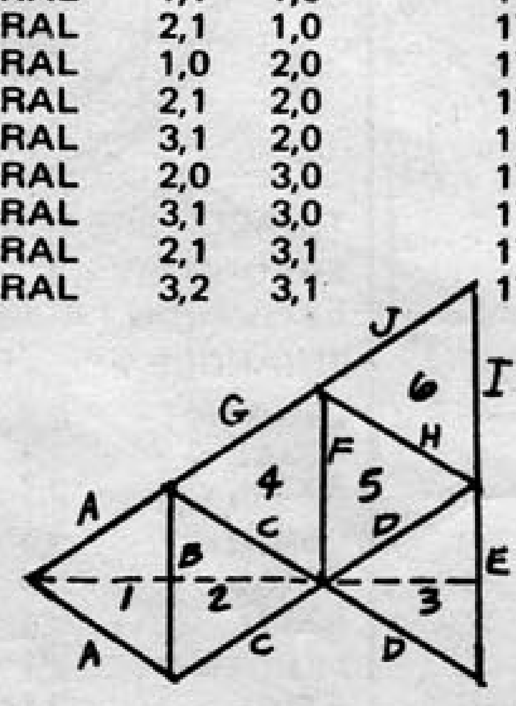


| 4-FREQUENCY ICOSAHEDRON | | | | CLASS II METHOD 1 |
|---|---|---|---|---|
| LENGTH-A | 0,0 | 1,0 | | .3091073 |
| LENGTH-B | 2,1 | 1,0 | | .3466883 |
| LENGTH-E | 1,0 | 2,0 | | .3403424 |
| LENGTH-D | 2,1 | 2,0 | | .3628433 |
| LENGTH-C | 1,1 | 1,0 | | .3590112 |
| AXIAL | 0.0 | 1,0 | 0,0 | 81.10908 |
| AXIAL | 0.0 | 1,0 | 1,1 | 79.65903 |
| AXIAL | 0.0 | 1,0 | 2,1 | 80.01768 |
| AXIAL | 0.0 | 2,0 | 1,0 | 80.20222 |
| AXIAL | 0.0 | 2,0 | 2,1 | 79.54741 |
| FACE | 1,1 | 0,0 | 1,0 | 71.00277 |
| FACE | 0,0 | 1,0 | 1,1 | 54.49861 |
| FACE | 1,1 | 1,0 | 2,1 | 58.81706 |
| FACE | 1,1 | 2,1 | 1,0 | 62.36587 |
| FACE | 1,0 | 2,1 | 2,0 | 57.27357 |
| FACE | 2,1 | 1,0 | 2,0 | 63.75086 |
| FACE | 1,0 | 2,0 | 2,1 | 58.97555 |
| DIHEDRAL | 0,0 | 1,0 | | 167.1862 |
| DIHEDRAL | 1,1 | 1,0 | | 170.9164 |
| DIHEDRAL | 2,1 | 1,0 | | 167.8084 |
| DIHEDRAL | 1,0 | 2,0 | | 167.2566 |
| DIHEDRAL | 2,1 | 2,0 | | 169.5607 |

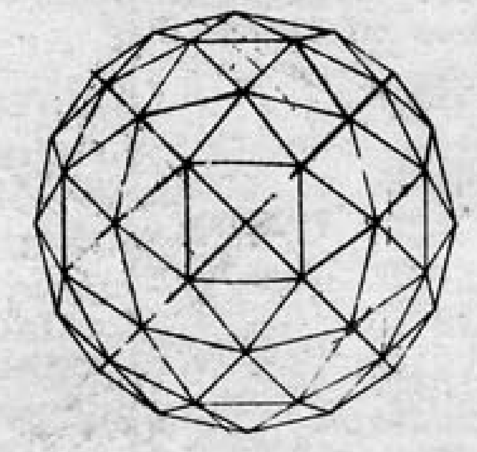




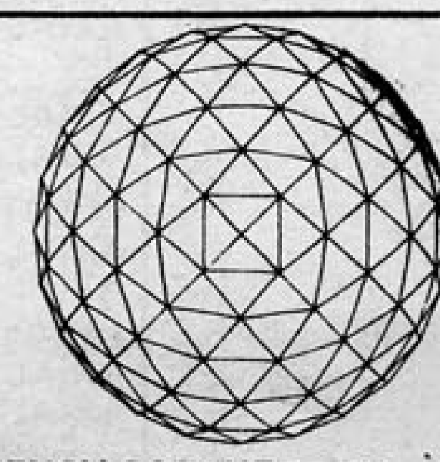
| 6-FREQUENCY ICOSAHEDRON | | | | CLASS II METHOD 1 |
|---|---|---|---|---|
| LENGTH-A | 0,0 | 1,0 | | .1999068 |
| LENGTH-B | 1,1 | 1,0 | | .2338277 |
| LENGTH-C | 2,1 | 1,0 | | .2204259 |
| LENGTH-G | 1,0 | 2,0 | | .2236135 |
| LENGTH-F | 2,1 | 2,0 | | .2438120 |
| LENGTH-H | 3,1 | 2,0 | | .2311914 |
| LENGTH-J | 2,0 | 3,0 | | .2275411 |
| LENGTH-I | 3,1 | 3,0 | | .2376603 |
| LENGTH-D | 2,1 | 3,1 | | .2383753 |
| LENGTH-E | 3,2 | 3,1 | | .2526047 |
| AXIAL | 0.0 | 1,0 | 0,0 | 84.26350 |
| AXIAL | 0.0 | 1,0 | 1,1 | 83.28597 |
| AXIAL | 0.0 | 1,0 | 2,1 | 83.67240 |
| AXIAL | 0.0 | 2,0 | 1,0 | 83.58052 |
| AXIAL | 0.0 | 2,0 | 2,1 | 82.99787 |
| AXIAL | 0.0 | 2,0 | 3,1 | 83.36200 |
| AXIAL | 0.0 | 3,0 | 2,0 | 83.46727 |
| AXIAL | 0.0 | 3,0 | 3,1 | 83.17540 |
| AXIAL | 0.0 | 3,1 | 2,1 | 83.15477 |
| AXIAL | 0.0 | 3,1 | 3,2 | 82.74402 |
| FACE | 1,1 | 0,0 | 1,0 | 71.58361 |
| FACE | 0,0 | 1,0 | 1,1 | 54.20819 |
| FACE | 1,1 | 1,0 | 2,1 | 57.96754 |
| FACE | 1,1 | 2,1 | 1,0 | 64.06490 |
| FACE | 1,0 | 2,1 | 2,0 | 57.32457 |
| FACE | 2,1 | 1,0 | 2,0 | 66.60298 |
| FACE | 1,0 | 2,0 | 2,1 | 56.07243 |
| FACE | 2,1 | 2,0 | 3,1 | 60.17371 |
| FACE | 2,1 | 3,1 | 2,0 | 62.53881 |
| FACE | 2,0 | 2,1 | 3,1 | 57.28745 |
| FACE | 2,0 | 3,1 | 3,0 | 58.04666 |
| FACE | 3,1 | 2,0 | 3,0 | 62.40113 |
| FACE | 2,0 | 3,0 | 3,1 | 59.55219 |
| FACE | 3,2 | 2,1 | 3,1 | 63.99017 |
| FACE | 2,1 | 3,1 | 3,2 | 58.00490 |
| DIHEDRAL | 0,0 | 1,0 | | 171.6929 |
| DIHEDRAL | 1,1 | 1,0 | | 174.4714 |
| DIHEDRAL | 2,1 | 1,0 | | 171.7439 |
| DIHEDRAL | 1,0 | 2,0 | | 171.7234 |
| DIHEDRAL | 2,1 | 2,0 | | 173.2939 |
| DIHEDRAL | 3,1 | 2,0 | | 171.7906 |
| DIHEDRAL | 2,0 | 3,0 | | 171.8081 |
| DIHEDRAL | 3,1 | 3,0 | | 172.8261 |
| DIHEDRAL | 2,1 | 3,1 | | 171.7525 |
| DIHEDRAL | 3,2 | 3,1 | | 172.8762 |



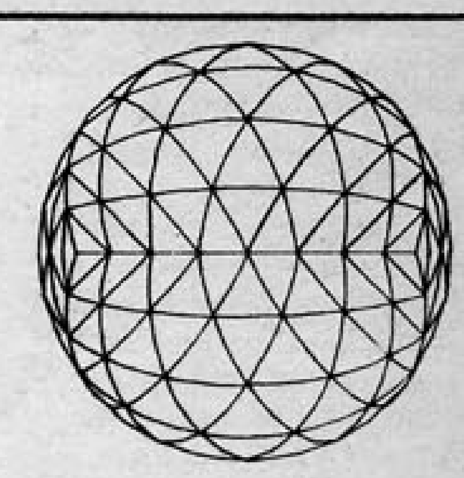
Figures below are for domes generated from the tetrahedron and octahedron. They are not as round as domes generated from the icosahedron. The octahedron forms a natural truncation at the hemisphere. Dyna Domes uses a 4-frequency octahedron breakdown for their domes. For assembly diagram see vertex identification diagram, p. 108.



| 4-FREQUENCY OCTAHEDRON | | | | CLASS I METHOD 1 |
|---|---|---|---|---|
| LENGTH-B | 1,1 | 1,0 | | .4472135 |
| LENGTH-D | 2,1 | 2,0 | | .5176380 |
| LENGTH-C | 3,1 | 3,0 | | .4388710 |
| LENGTH-E | 3,2 | 3,1 | | .5773502 |
| LENGTH-A | 4,1 | 4,0 | | .3203644 |
| LENGTH-F | 4,2 | 4,1 | | .4595058 |
| AXIAL | 0.0 | 1,0 | 1,1 | 77.07903 |
| AXIAL | 0.0 | 2,0 | 2,1 | 74.99999 |
| AXIAL | 0.0 | 3,0 | 3,1 | 77.32411 |
| AXIAL | 0.0 | 3,1 | 3,2 | 73.22134 |
| AXIAL | 0.0 | 4,0 | 4,1 | 80.78252 |
| AXIAL | 0.0 | 4,1 | 4,2 | 76.71747 |
| FACE | 1,1 | 0,0 | 1,0 | 88.52971 |
| FACE | 1,1 | 2,1 | 1,0 | 61.26167 |
| FACE | 2,1 | 1,0 | 2,0 | 70.32347 |
| FACE | 2,1 | 3,1 | 2,0 | 56.10466 |
| FACE | 3,1 | 2,0 | 3,0 | 52.97068 |
| FACE | 3,1 | 4,1 | 3,0 | 59.36916 |
| FACE | 3,2 | 2,l | 3,1 | 59.99999 |
| FACE | 3,2 | 4,2 | 3,1 | 67.79066 |
| FACE | 4,1 | 3,0 | 4,0 | 45.73513 |
| FACE | 4,2 | 3,1 | 4,1 | 56.70583 |
| DIHEDRAL | 1,1 | 1,0 | | 172.4355 |
| DIHEDRAL | 2,1 | 2,0 | | 164.1306 |
| DIHEDRAL | 3,1 | 3,0 | | 162.5781 |
| DIHEDRAL | 3,2 | 3,1 | | 162.9038 |
| DIHEDRAL | 4,1 | 4,0 | | 161.7990 |
| DIHEDRAL | 4,2 | 4,1 | | 162.1625 |



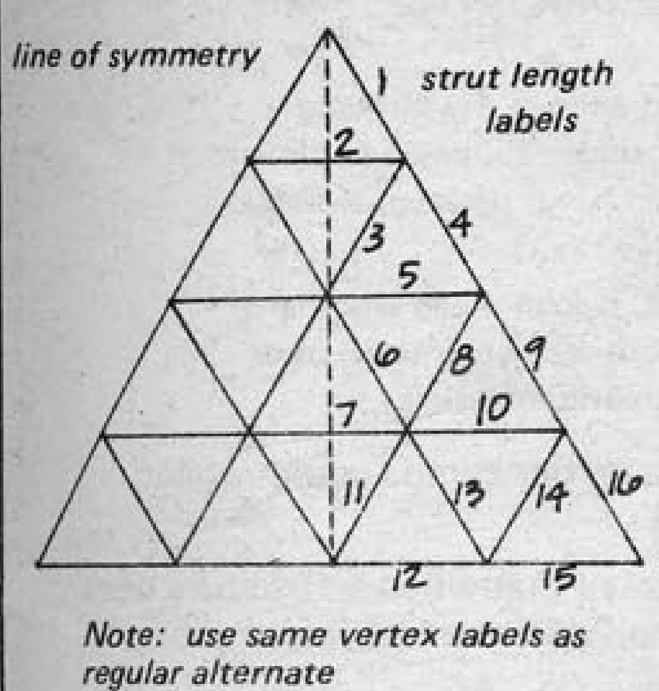
| 6-FREQUENCY OCTAHEDRON | | | | CLASS I METHOD 1 |
|---|---|---|---|---|
| LENGTH | 1,1 | 1,0 | | .2773501 |
| LENGTH | 2,1 | 2,0 | | .3203644 |
| LENGTH | 3,1 | 3,0 | | .3319301 |
| LENGTH | 3,2 | 3,1 | | .3779644 |
| LENGTH | 4,1 | 4,0 | | .2960307 |
| LENGTH | 4,2 | 4,1 | | .3851750 |
| LENGTH | 5;1 | 5,0 | | .2419696 |
| LENGTH | 5,2 | 5,1 | | .3319301 |
| LENGTH | 5,3 | 5,2 | | .3779644 |
| LENGTH | 6,1 | 6,0 | | .1970752 |
| LENGTH | 6,2 | 6,1 | | .2654663 |
| LENGTH | 6,3 | 6,2 | | .3203644 |
| AXIAL | 0.0 | 1,0 | 1,1 | 82.02881 |
| AXIAL | 0.0 | 2,0 | 2,1 | 80.78252 |
| AXIAL | 0.0 | 3,0 | 3,1 | 80.44669 |
| AXIAL | 0.0 | 3,l | 3,2 | 79.10660 |
| AXIAL | 0.0 | 4,0 | 4,1 | 81.48806 |
| AXIAL | 0.0 | 4,1 | 4,2 | 78.89616 |
| AXIAL | 0.0 | 5.0 | 5,1 | 83.05105 |
| AXIAL | 0.0 | 5,1 | 5,2 | 80.44669 |
| AXIAL | 0.0 | 5,2 | 5,3 | 79.10660 |
| AXIAL | 0.0 | 6,0 | 6,1 | 84.34503 |
| AXIAL | 0.0 | 6,1 | 6,2 | 82.37243 |
| AXIAL | 0.0 | 6,2 | 6,3 | 80.78252. |
| FACE | 1,1 | 0,0 | 1,0 | 89.44366 |
| FACE | 1,1 | 2,1 | 1,0 | 69.93465 |
| FACE | 2,1 | 1,0 | 2,0 | 78.14680 |
| FACE | 2,1 | 3,1 | 2,0 | 61.03260 |
| FACE | 3,1 | 2,0 | 3,0 | 65.02343 |
| FACE | 3,1 | 4,1 | 3,0 | 55.29554 |
| FACE | 3,2 | 2,1 | 3,1 | 69.40889 |
| FACE | 3,2 | 4,2 | 3,1 | 58.76529 |
| FACE | 4,1 | 3,0 | 4,0 | 53.94395 |
| FACE | 4,1 | 5,1 | 4,0 | 53.94395 |
| FACE | 4,2 | 3,1 | 4,1 | 60.61734 |
| FACE | 4,2 | 5,2 | 4,1 | 60.61734 |
| FACE | 5,1 | 4,0 | 5,0 | 47.66244 |
| FACE | 5,1 | 6,1 | 5,0 | 55.03267 |
| FACE | 5,2 | 4,1 | 5,1 | 55.29554 |
| FACE | 5,2 | 6,2 | 5,1 | 65.02343 |
| FACE | 5,3 | 4,2 | 5,2 | 58.76529 |
| FACE | 5,3 | 6,3 | 5,2 | 69.40889 |
| FACE | 6,1 | 5,0 | 6,0 | 45.27816 |
| FACE | 6,2 | 5,1 | 6,1 | 54.19075 |
| FACE | 6,2 | 5,2 | 6,2 | 61.03260 |
| DIHEDRAL | 1,1 | 1,0 | | 176.9902 |
| DIHEDRAL | 2,1 | 2,0 | | 172.8942 |
| DIHEDRAL | 3,l | 3,0 | | 168.8103 |
| DIHEDRAL | 3,2 | 3,1 | | 169.1513 |
| DIHEDRAL | 4,1 | 4,0 | | 167.4891 |
| DIHEDRAL | 4,2 | 4,1 | | 167.3106 |
| DIHEDRAL | 5,1 | 5,0 | | 168.7345 |
| DIHEDRAL | 5,2 | 5,1 | | 168.8103 |
| DIHEDRAL | 5,3 | 5,2 | | 169.1513 |
| DIHEDRAL | 6,1 | 6,0. | | 168.7447 |
| DIHEDRAL | 6,2 | 6,1 | | 168.9111 |
| DIHEDRAL | 6,3 | 6,2 | | 169.6921 |



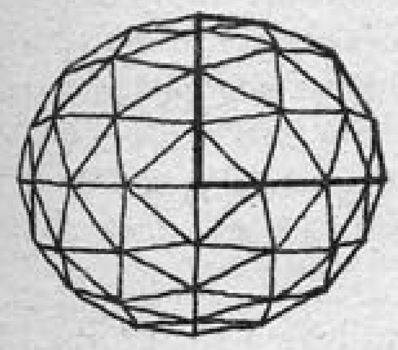
| 8-FREQUENCY TETRAHEDRON | | | | |
|---|---|---|---|---|
| LENGTH | 1,1 | 1,0 | | .2425356 |
| LENGTH | 2,1 | 2,0 | | .2917975 |
| LENGTH | 3,1 | 3,0 | | .3319301 |
| LENGTH | 3,2 | 3,1 | | .3779644 |
| LENGTH | 4,1 | 4,0 | | .3203644 |
| LENGTH | 4,2 | 4,1 | | .4595058 |
| LENGTH | 5,1 | 5,0 | | .2491473 |
| LENGTH | 5,2 | 5,1 | | .4388710 |
| LENGTH | 5,3 | 5,2 | | .5773502 |
| LENGTH | 6,1 | 6,0 | | .1898393 |
| LENGTH | 6,2 | 6,1 | | .3319301 |
| LENGTH | 6,3 | 6,2 | | .5176380 |
| LENGTH | 7,1 | 7,0 | | .1598888 |
| LENGTH | 7,2 | 7,1 | | .2503401 |
| LENGTH | 7,3 | 7,2 | | .3750475 |
| LENGTH | 7,4 | 7,3 | | .4472136 |
| LENGTH | 8,1 | 8,0 | | .1403741 |
| LENGTH | 8,2 | 8,1 | | .1990172 |
| LENGTH | 8,3 | 8,2 | | .2747709 |
| LENGTH | 8,4 | 8,3 | | .3382039 |
| AXIAL | 0.0 | 1,0 | 1,1 | 83.03471 |
| AXIAL | 0.0 | 2,0 | 2,1 | 81.61066 |
| AXIAL | 0.0 | 3,0 | 3,1 | 80.44669 |
| AXIAL | 0.0 | 3,1 | 3,2 | 79.10660 |
| AXIAL | 0.0 | 4,0 | 4,1 | £0.78252 |
| AXIAL | 0.0 | 4,1 | 4,2 | 76.71747 |
| AXIAL | 0.0 | 5,0 | 5,1 | 82.84385 |
| AXIAL | 0.0 | 5,1 | 5,2 | 77.32411 |
| AXIAL | 0.0 | 5,2 | 5,3 | 73.22134 |
| AXIAL | 0.0 | 6,0 | 6,1 | 84.55329 |
| AXIAL | 0.0 | 6,1 | 6,2 | 80.44669 |
| AXIAL | 0.0 | 6,2 | 6,3 | 74.99999 |
| AXIAL | 0.0 | 7,0 | 7,1 | 85.41462 |
| AXIAL | 0.0 | 7,1 | 7,2 | 82.80941 |
| AXIAL | 0.0 | 7,2 | 7,3 | 79.19168 |
| AXIAL | 0.0 | 7,3 | 7,4 | 77.07903 |
| AXIAL | 0.0 | 8,0 | 8,1 | 85.97526 |
| AXIAL | 0.0 | 8,1 | 8,2 | 84.28912 |
| AXIAL | 0.0 | 8,2 | 8,3 | 82.10341 |
| AXIAL | 0.0 | 8,3 | 8,4 | 80.26438 |
| FACE | 1,1 | 0,0 | 1,0 | 119.5123 |
| FACE | 1,1 | 2,1 | 1,0 | 98.65558 |
| FACE | 2,1 | 1,0 | 2,0 | 108.2910 |
| FACE | 2,1 | 3,1 | 2,0 | 81.79592 |
| FACE | 3,1 | 2,0 | 3,0 | 89.25280 |
| FACE | 3,1 | 4,1 | 3,0 | 60.31269 |
| FACE | 3,2 | 2,1 | 3,1 | 98.03357 |
| FACE | 4,1 | 3,0 | 4,0 | 64.02030 |
| FACE | 4,1 | 5,1 | 4,0 | 45.73513 |
| FACE | 4,2 | 3,1 | 4,1 | 80.82667 |
| FACE | 3,2 | 4,2 | 3,1 | 69.40889 |
| FACE | 4,2 | 5,2 | 4,1 | 56.70583 |
| FACE | 5,1 | 4,0 | 5,0 | 44.35585 |
| FACE | 5,1 | 6,1 | 5,0 | 40.69851 |
| FACE | 5,2 | 4,1 | 5,1 | 59.36916 |
| FACE | 5,2 | 6,2 | 5,1 | 52.97068 |
| FACE | 5,3 | 4,2 | 5,2 | 67.79066 |
| FACE | 5,3 | 6,3 | 5,2 | 59.99999 |
| FACE | 6,1 | 5,0 | 6,0 | 34.88121 |
| FACE | 6,1 | 7,1 | 6,0 | 40.08534 |
| FACE | 6,2 | 5,1 | 6,1 | 45.48972 |
| FACE | 6,2 | 7,2 | 6,1 | 55.29554 |
| FACE | 6,3 | 5,2 | 6,2 | 56.10466 |
| FACE | 6,3 | 7,3 | 6,2 | 70.32347 |
| FACE | 7,1 | 6,0 | 7,0 | 31.34965 |
| FACE | 7,1 | 8,1 | 7,0 | 40.67220 |
| FACE | 7,2 | 6,1 | 7,1 | 40.98321 |
| FACE | 7,2 | 8,2 | 7,1 | 58.11872 |
| FACE | 7,3 | 6,2 | 7,2 | 53.68360 |
| FACE | 7,3 | 8,3 | 7,2 | 78.98877 |
| FACE | 7,4 | 6,3 | 7,3 | 61.26167 |
| FACE | 7,4 | 8,4 | 7,3 | 88.52971 |
| FACE | 8,1 | 7,0 | 8,0 | 30.24383 |
| FACE | 8,2 | 7,1 | 8,1 | 40.35929 |
| FACE | 8,3 | 7,2 | 8,2 | 55.86596 |
| FACE | 8,4 | 7,3 | 8,3 | 71.62383 |
| DIHEDRAL | 1,1 | 1,0 | | 174.9689 |
| DIHEDRAL | 2,1 | 2,0 | | 178.4242 |
| DIHEDRAL | 3,1 | 3,0 | | 174.3684 |
| DIHEDRAL | 3,2 | 3,1 | | 177.4101 |
| DIHEDRAL | 4,1 | 4,0 | | 166.3640 |
| DIHEDRAL | 4,2 | 4,1 | | 168.8965 |
| DIHEDRAL | 5,1 | 5,0 | | 164.2287 |
| DIHEDRAL | 5,2 | 5,1 | | 162.5781 |
| DIHEDRAL | 5,3 | 5,2 | | 162.9038 |
| DIHEDRAL | 6,1 | 6,0 | | 165.6335 |
| DIHEDRAL | 6,2 | 6,1 | | 163.7834 |
| DIHEDRAL | 6,3 | 6,2 | | 164.1306 |
| DIHEDRAL | 7,1 | 7,0 | | 167.0795 |
| DIHEDRAL | 7,2 | 7,1 | | 167.1492 |
| DIHEDRAL | 7,3 | 7,2 | | 169.8046 |
| DIHEDRAL | 7,4 | 7,3 | | 172.4355 |
| DIHEDRAL | 8,1 | 8,0 | | 166.1374 |
| DIHEDRAL | 8,2 | 8,1 | | 166.4841 |
| DIHEDRAL | 8,3 | 8,2 | | 169.2092 |
| DIHEDRAL | 8,4 | 8,3 | | 173.4652 |

## OCTAHEDRON ELLIPTICAL

Using the octahedron means that there is only one principle triangle involved. All the rest are the same. It can be truncated perfectly zenith-to-zenith to produce a shape such as the paper model on p. 124 or to sit high like the egg. In either case, the octahedronal form has the distinguishing ability to fuse to rectilinear structures. An alternate breakdown is used.



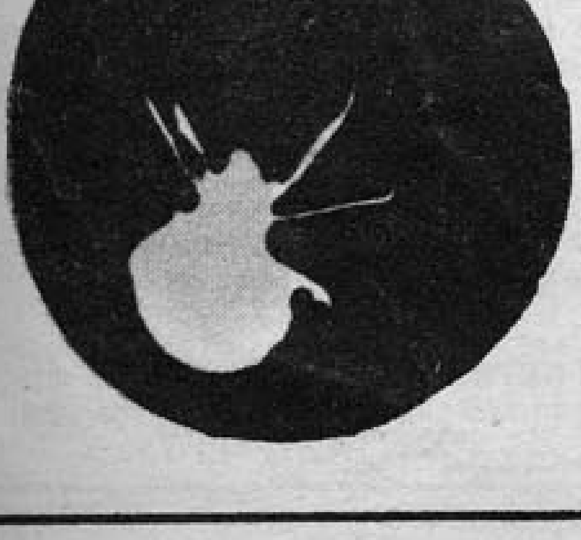

*Note: use same vertex labels as regular alternate*

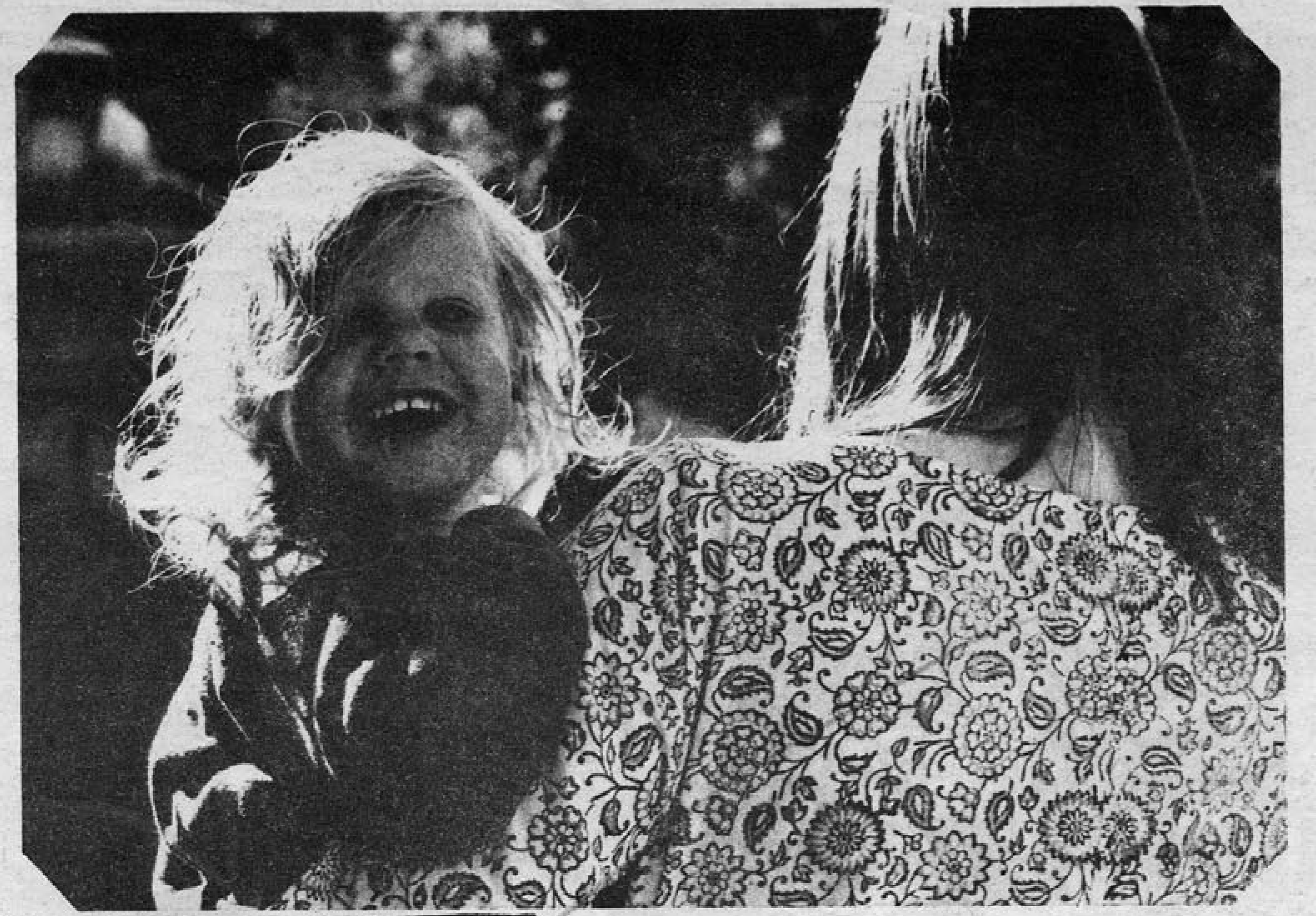


EXPANDED OCTAHEDRON
FREQUENCY = 4
EXPANSION = 1.61800

| | | | |
|---|---|---|---|
| LENGTH-1 | 0,0 | 1,0 | .326946 |
| AXIAL | 1,0 | | 76.3723 |
| AXIAL | 0,0 | | 75.2881 |
| LENGTH-2 | 1,1 | 1,0 | .447213 |
| AXIAL | 1,0 | | 70.3873 |
| AXIAL | 1,1 | | 70.3873 |
| LENGTH-3 | 1,0 | 2,1 | .469976 |
| AXIAL | 2,1 | | 74.5005 |
| AXIAL | 1,0 | | 72.0855 |
| LENGTH-4 | 1,0 | 2,0 | .552780 |
| AXIAL | 2,0 | | 76.7174 |
| AXIAL | 1,0 | | 73.3400 |
| LENGTH-5 | 2,1 | 2,0 | .536012 |
| AXIAL | 2,0 | | 72.5012 |
| AXIAL | 2,1 | | 70.9763 |
| LENGTH-6 | 2,1 | 3,1 | .776522 |
| AXIAL | 3,1 | | 76.9018 |
| AXIAL | 2,1 | | 73.7454 |
| LENGTH-7 | 3,2 | 3,1 | .577350 |
| AXIAL | 3,1 | | 62.2539 |
| AXIAL | 3,2 | | 72.2539 |
| LENGTH-8 | 2,0 | 3,1 | .642227 |
| AXIAL | 3,1 | | 77.2756 |
| AXIAL | 2,0 | | 75.4659 |
| LENGTH-9 | 2,0 | 3,0 | .677009 |
| AXIAL | 3,0 | | 80.7354 |
| AXIAL | 2,0 | | 79.1875 |
| LENGTH-10 | 3,1 | 3,0 | .454211 |
| AXIAL | 3,0 | | 77.3557 |
| AXIAL | 3,1 | | 77.0637 |
| LENGTH-11 | 3,1 | 4,2 | .733214 |
| AXIAL | 4,2 | | 79.4716 |
| AXIAL | 3,1 | | 78.8762 |
| AXIAL | | | |
| LENGTH-12 | 4,2 | 4,1 | .459505 |
| AXIAL | 4,1 | | 76.7174 |
| AXIAL | 4,2 | | 76.7174 |
| LENGTH-13 | 3,1 | 4,1 | .679898 |
| AXIAL | 4,1 | | 81.8569 |
| AXIAL | 3,1 | | 81.3987 |
| LENGTH-14 | 3,0 | 4,1 | .601491 |
| AXIAL | 4,1 | | 80.4299 |
| AXIAL | 3,0 | | 80.1167 |
| LENGTH-15 | 4,1 | 4,0 | .320364 |
| AXIAL | 4,0 | | 80.7825 |
| AXIAL | 4,1 | | 80.7825 |
| LENGTH-16 | 3,0 | 4,0 | .514223 |
| AXIAL | 4,0 | | 84.2726 |
| AXIAL | 3,0 | | 84.0863 |

Half of this stretched octahedron can be put together with the spherical 4-frequency octahedron on the opposite page. There are paper models of both of these octahedrons on p. 124.





# USEFUL MATH

# TRIG

## RIGHT-ANGLED TRIGONOMETRIC FUNCTIONS

Right-angled trigonometric functions:
The trig functions are the ratios of sides of right triangles.

Function

$\sin \phi = \frac{\text{side opposite}}{\text{hypotenuse}} = \frac{a}{c}$

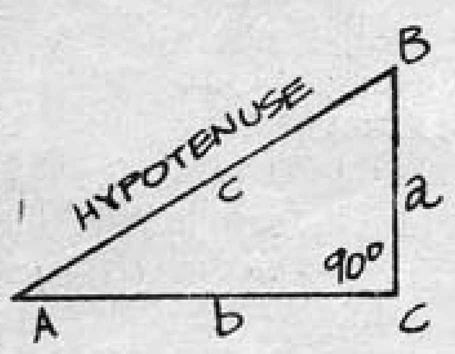
$\cos \phi = \frac{\text{side adjacent}}{\text{hypotenuse}} = \frac{b}{c}$

$\tan \phi = \frac{\text{side opposite}}{\text{side adjacent}} = \frac{a}{b}$

$\cot \phi = \frac{\text{side adjacent}}{\text{side opposite}} = \frac{b}{a}$

$\sec \phi = \frac{\text{hypotenuse}}{\text{side adjacent}} = \frac{c}{b}$

$\csc \phi = \frac{\text{hypotenuse}}{\text{side opposite}} = \frac{c}{a}$

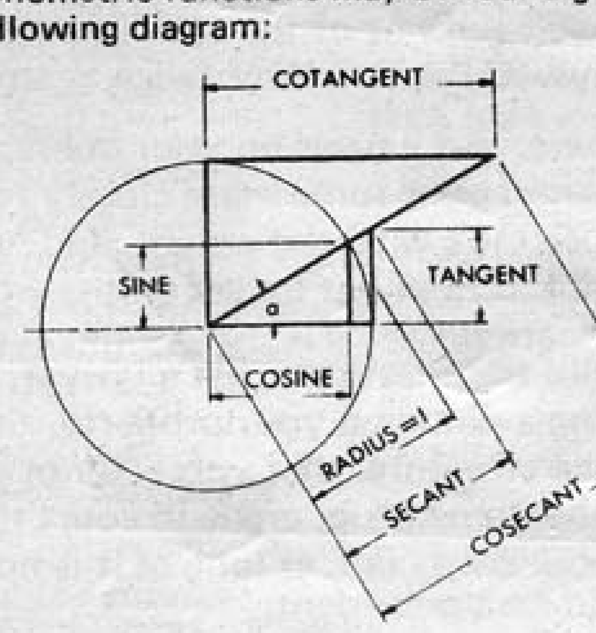



***Note: See simple pocketbook Trig tables in bibliography.***

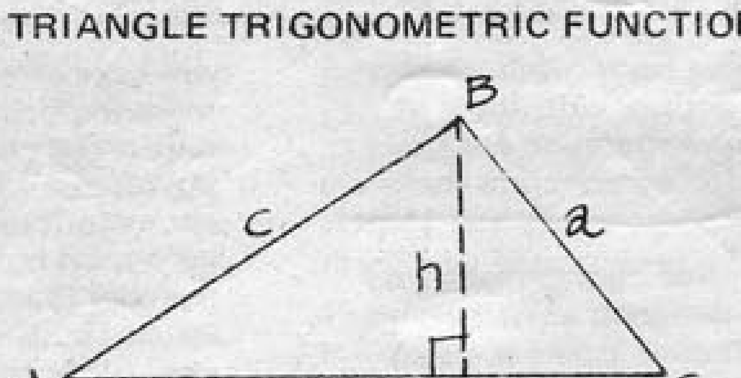
$c^2 = a^2 + b^2$

$180° = 90° + \phi + \theta$

The trigonometric functions may be found graphically with the aid of the following diagram:




## OBLIQUE TRIANGLE TRIGONOMETRIC FUNCTIONS




Law of sines:
Lengths of the sides of a triangle are proportional to the sines of the angles opposite them:

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

Law of cosines:
The square of the length of a side of a triangle equals the sum of the squares of the lengths of the other two sides minus twice the product of these two sides times the cosines of the angle between them.

$$a^2 = b^2 + c^2 - 2bc \cos A$$

$$b^2 = a^2 + c^2 - 2ac \cos B$$

$$c^2 = a^2 + b^2 - 2ab \cos C$$

# LUMBER MEASURE

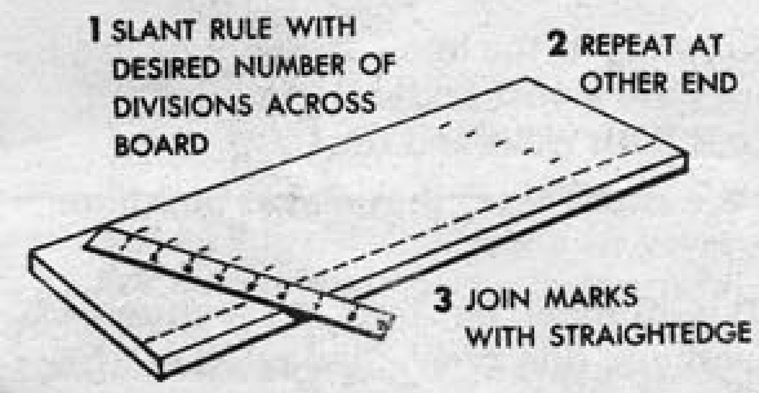
| SIZE (INCHES) | LENGTH IN FEET 10 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|
| 1 by 2 | 1⅔ | 2 | 2⅓ | 2⅔ | 3 |
| 1 by 3 | 2½ | 3 | 3½ | 4 | 4½ |
| 1 by 4 | 3⅓ | 4 | 4⅔ | 5⅓ | 6 |
| 1 by 6 | 5 | 6 | 7 | 8 | 9 |
| 1 by 8 | 6⅔ | 8 | 9⅓ | 10⅔ | 12 |
| 1 by 10 | 8⅓ | 10 | 11⅔ | 13⅓ | 15 |
| 1 by 12 | 10 | 12 | 14 | 16 | 18 |
| 2 by 4 | 6⅔ | 8 | 9⅓ | 10⅔ | 12 |
| 2 by 6 | 10 | 12 | 14 | 16 | 18 |
| 2 by 8 | 13⅓ | 16 | 18⅔ | 21⅓ | 24 |
| 2 by 10 | 16⅔ | 20 | 23⅓ | 26⅔ | 30 |
| 2 by 12 | 20 | 24 | 28 | 32 | 36 |
| 3 by 10 | 25 | 30 | 35 | 40 | 45 |
| 3 by 12 | 30 | 36 | 42 | 48 | 54 |
| 4 by 4 | 13⅓ | 16 | 18⅔ | 21⅓ | 24 |
| 6 by 6 | 30 | 36 | 42 | 48 | 54 |

BOARD FEET

# DIVIDING BOARD *into* EQUAL PIECES

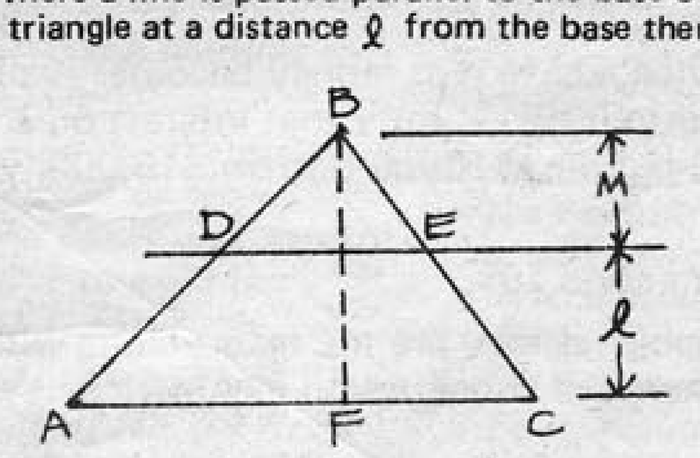
1 SLANT RULE WITH DESIRED NUMBER OF DIVISIONS ACROSS BOARD

2 REPEAT AT OTHER END



3 JOIN MARKS WITH STRAIGHTEDGE

Where a line is passed parallel to the base of a triangle at a distance $\ell$ from the base then:




$$\frac{DA}{BA} = \frac{EC}{BC} = \frac{\ell}{BF}$$

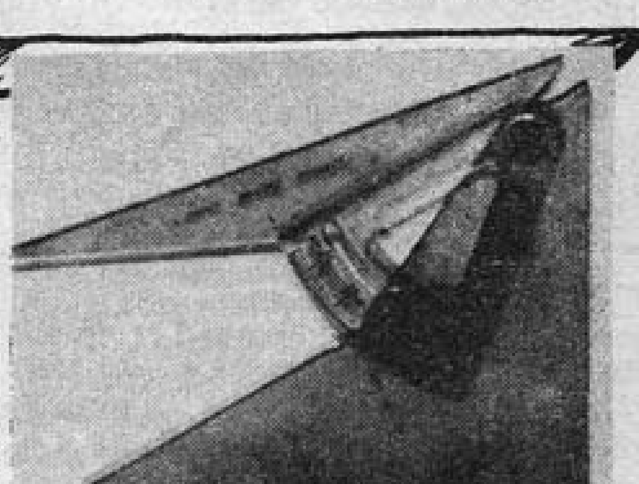
$$\frac{BD}{BA} = \frac{BE}{BC} = \frac{DE}{AC} = \frac{M}{BF}$$

This holds true also in 3-D space and may be used for calculating cut-off dimensions.

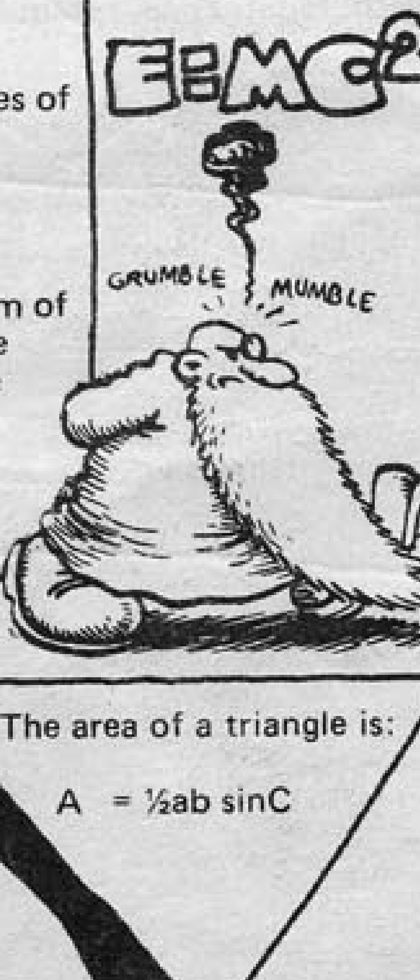
## Decimal Equivalents of Fractions

*Use these to calculate fractions of an inch from the decimal obtained by multiplying radius times chord factors.*

| | | |
|---|---|---|
| 1/32 | = | .03125 |
| 1/16 | = | .06250 |
| 3/32 | = | .09375 |
| 1/8 | = | .12500 |
| 5/32 | = | .15625 |
| 3/16 | = | .18750 |
| 7/32 | = | .21875 |
| 1/4 | = | .25000 |
| 9/32 | = | .28125 |
| 5/16 | = | .31250 |
| 11/32 | = | .34375 |
| 3/8 | = | .37500 |
| 13/32 | = | .40625 |
| 7/16 | = | .43750 |
| 15/32 | = | .46875 |
| 1/2 | = | .50000 |
| 17/32 | = | .53125 |
| 9/16 | = | .56250 |
| 19/32 | = | .59375 |
| 5/8 | = | .62500 |
| 21/32 | = | .65625 |
| 11/16 | = | .68750 |
| 23/32 | = | .71875 |
| 3/4 | = | .75000 |
| 25/32 | = | .78125 |
| 13/16 | = | .81250 |
| 27/32 | = | .84375 |
| 7/8 | = | .87500 |
| 29/32 | = | .90625 |
| 15/16 | = | .93750 |
| 31/32 | = | .96875 |
| 1 | = | 1.00000 |



**Angle marker useful in measuring all those wierd angles. Get one at a drafting store.**




$\pi = 3.14159265$

| | | |
|---|---|---|
| Circumference of circle | $2\pi r$ | r = radius |
| Area of circle | $\pi r^2$ | b = base |
| Area of sphere (skin) | $4\pi r^2$ | h = altitude |
| Volume of sphere | $4/3\pi r^3$ | |
| Area of triangle | 1/2 bh | |

Note: by doubling the diameter of a sphere, the surface area is increased by a factor of 4; the volume is increased by a factor of 8.

In any convex polyhedron, the number of faces (F), vertices (V) and edges (E) are related as follows:

$F + V = E + 2$

This formula can be used in checking domes which are not complete spheres: consider the open bottom as a single face polygon; the number of sides equals the number of members along the perimeter of the dome's framework.

Conversion of feet to meters/meters to feet:

1 ft = 0.3048 meters
1 meter = 3.28084 ft

The area of a triangle is:

A = ½ab sinC

# HOW TO DRAW AN ELLIPSE

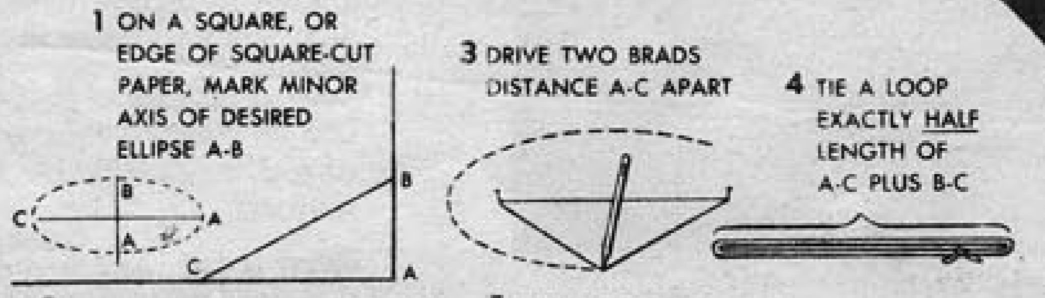
1 ON A SQUARE, OR EDGE OF SQUARE-CUT PAPER, MARK MINOR AXIS OF DESIRED ELLIPSE A-B

2 MARK LENGTH OF MAJOR AXIS FROM B TO C

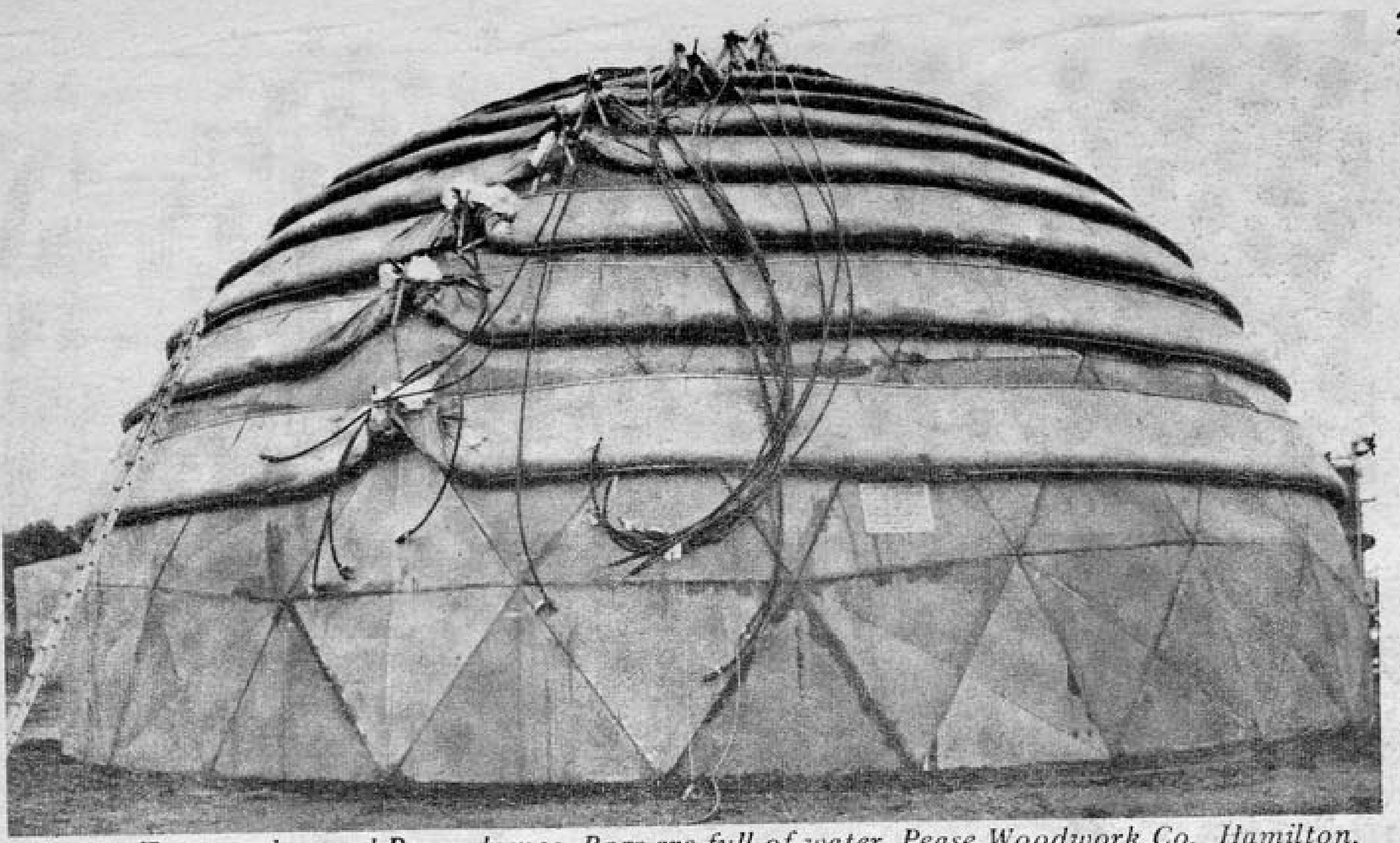
3 DRIVE TWO BRADS DISTANCE A-C APART

4 TIE A LOOP EXACTLY <u>HALF</u> LENGTH OF A-C PLUS B-C

5 WITH LOOP ON BRADS, SWING PENCIL INSIDE IT TO DRAW ELLIPSE




THANX TO B. Crumb



*Test on plywood Pease domes. Bags are full of water. Pease Woodwork Co., Hamilton, Ohio has some valuable test data, certified by H.C. Nutting Co., testing engineers, of Cincinatti, Ohio. Dyna Domes, of Phoenix, has also made extensive structural tests.*

# Building Inspector

Although building codes were probably originally designed to protect home buyers from slipshod contractors, they tend to discourage individual initiative, and force people into the position of dealing with the entire "craft and graft" building industry. If your structure is not covered in the building code manual, you generally must get an engineers approval before they will let you build. Building codes, and engineering deal for the most part with rectilinear structures, and the structural strength of domes cannot be explained in these terms.

I have always assumed that building inspectors are human and have much greater luck in explaining things to them, rather than fighting them. The farther you are from a city, the fewer problems you will encounter, but if your site does fall within the jurisdiction of local codes, these are some observations and experiences that may be helpful:

Building codes do not cover domes. There's nothing in the book about tension (the top of the dome, although rock solid, does not have a post under it). You don't need studs every 16", and the entire structure is both walls and roof.

In building your own dome you short-circuit the entire team that makes buildings, which includes:

1) architects and engineers. You may consult with them, but both the architecture and the engineering of a dome are simple and you don't have to pay 10 or 15% of the building costs to these two.
2) Union help. Not needed, as the customary handskills are not necessary.
3) Banks. You can build the shell, move in, then add to it as money becomes available. No mortgage enslavement. I was astounded to learn recently that interest on a typical mortgage loan *doubles* the cost of a building. If you borrow $15,000, you pay back, over the years, over $30,000.
4) Contractors. You are on your own, and this saves 10%.

When you bypass these interests, you're in trouble, as they are the team—along with building inspectors and materials dealers—in charge of construction in America. You have the choice of several alternatives.

1) You may be in an area not subject to inspectors. No problem here.
2) If you do come under the codes, several possibilities:
   a) *exemption:* sometimes the codes, or local county ordinances allow you to build a barn, greenhouse, studio, temporary building, tent, a sculpture, etc., without a permit. Check codes and talk to inspectors—be vague until you find out how to classify it. Start by using telephone.
   b) *summer camp:* in California (perhaps also in other states), tents intended for use at a summer camp do not fall under jurisdiction of the building inspector. Get Calif. Organized Camps pamphlet:

      "Laws and Regulations Relating to Organized Camps—Excerpts from the California Health and Safety Code and the California Administrative Codes—1968". Can be obtained from State of California, Dept. of Public Health, 2151 Berkeley Way, Berkeley, CA 94704.

      The health department is in charge of camps, and will use the building inspector for advice. However, "tent platforms" under 25' any one dimension can be built without usual permits or fees. Perhaps your dome qualifies as a tent:

      "Whenever the term tent or tent structure is used, it shall mean any shelter of which 25% or more of the walls, or roof, or both are constructed of or covered by or protected by, canvas or any other fabric materials . . ."

      Be cool on this one, as a rush of hastily-concocted summer camps could rescind the law.
   c) *strength test:* Section 107, Uniform Building Code says that when a structure does not come within the code, the building inspector shall devise a test for structural strength:

      Whenever there is insufficient evidence in compliance with the provisions of this code or evidence that any material or any construction does not conform to the requirements of this code, or in order to substantiate claims for alternate materials or methods of construction, the Building Official may require tests as proof of compliance to be made at the expense of the owner or his agent by an approved agency. . . . If there are no appropriate test methods specified in this Code, the Building Official shall determine the test procedure. . . . "

      The inspector may interpret this as meaning that you have to hire a structural engineer, but it looks as if it is up to him to devise a test. A simple strength test is to load a top section of the dome with sandbags. Since the dome is spherical, and more or less equally strong throughout the entire skin, whatever load you place on the top is equivalent to the same force wind blowing from the side. Perhaps easier than sandbags would be some kind of containers you'd fill with water—easier than lugging sandbags.

      Some extensive structural tests of plywood domes were made by The H. C. Nutting Co., 4120 Airport Road, Cincinnati, Ohio 45226, in 1958-59.

      Two Pease domes were tested—similar in construction to the Big Sur dome, p. 16 One was 26' diameter with 2 x 4 strut space-frames, the other was 39' diameter, with 2 x 2 strut space-frames. Both were sheathed with 5/16" plywood.

      The domes sustained loads of 100-120 lbs per sq. ft., sand loaded onto the apex of the dome and its six converging triangles. In another test, a North American AT–6 Army trainer with 650 hp Pratt-Whitney engine was used to produce a wind of hurricane force (in excess of 70 mph). The airplane was backed up to the dome, and tried from different angles. The reports include detailed tabulations of deflections. The wind machine didn't faze the dome.

      The Uniform Building Code requires *any horizontal projection* in a dwelling to support a live load of 40 lbs per sq. ft. The structure must also support "dead load"—weight of the structure itself. So this type dome, with only 5/16" plywood skin, is over twice as strong as required by the codes.
   d) *mobile home:* put wheels on your dome. Regulations on mobile homes are much more lenient, and a dome more closely resembles a mobile home than a typical heavy house: it's 1/10 the weight, and with proper design, you can easily move it. I don't think it even has to *roll* on the wheels; just putting them on may qualify for the classification.
3) Someone could try a test case; get a lawyer, write the building dept., tell them you're building a dome on your property, that you absolve them of any legal liability for the structure, that you will not sell the dome. If there is legal action after the dome is up, argue in court that you have a constitutional right to build on your own land, as long as it is not for resale. If such a case won in court, it could be a precedent.

Whatever you do, try to make it possible for more domes to be built in your area.

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Triodetic Structures Limited is a Canadian firm that builds domes, other three dimensional structures and space frames. They handle design, engineering, and erection. They have a patented hub, although it's probably too expensive for relatively small projects. Following are some pictures and sketches of their structures, and extracts from a paper: "Eighty Typical Questions and Answers Concerning Triodetic Structures, Space Frames, and Shells", courtesy of H. G. Fentiman.

*What is the structural effect of cladding?* Beneficial; but usually ignored. It has been thought of to use a steel framed space frame shell as a form and reinforcing system for a concrete shell that would then be composite. This should be efficient and economic; it has not yet been found appropriate to do.

*How is account made for moments in members?* Much as with conventional design of members in trusses etc. A trial section is chosen and checked for combined loads: axial load, bending due to transverse load etc. Checking is done with the expression:

$$\frac{f_a}{F_a} + \frac{f_b}{F_b} = 1$$

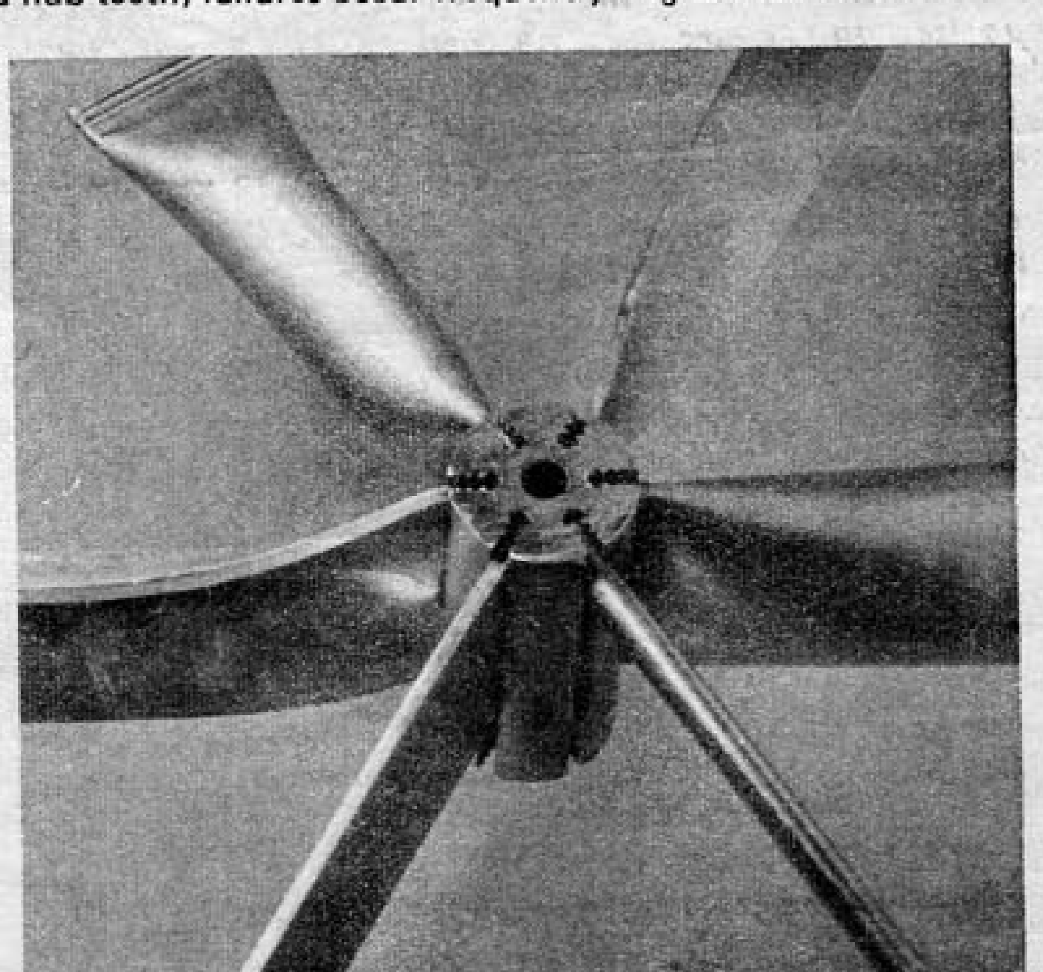
and the check is usually made three times, once at the end and twice at mid-span. This is required because the stresses $f_a$ and $f_b$ may vary, especially bending stresses, and because $F_a$ should be calculated for zero slenderness at the ends, for $L_u$ = length for checking the tendency to buckle in direction restrained by hubs and flattened ends.

*What are the various methods of analysis?* In brief there are two: continuum analysis and discrete member analysis. In the latter the space frame is treated as a three-dimensional truss and every bar force is determined. In the former analysis is made on a continua that behaves in the same way as the space frame. The latter seems easier, and seems to work well.

*What is the useful maximum 1/r ratio for tubes?* Tubes have been used with slenderness ratios up to 150. Practical limits because of loss of compressive strength are about 120.

*How is the Bucharest collapse explained?* It seems to have been a simple buckling failure of the whole shell. Eccentricities at the joints do not seem to have been important. Lederer, the progenitor of this type of dome, in his discussion to the Feb. 65 ASCE paper does not dispute the findings in the paper. There have been rumours of buckling troubles, especially during construction, with some other light dome structures. Buckling seems to govern design for space frame domes over about 100 ft span: reinforced concrete shells are much less sensitive to buckling.

*What order of stress levels are developed in hub connections, and what is normal mode of failure?* Hubs are designed to be stronger than tubes. Stresses are substantially less than in tubes as tubes approach failure. Normal joint failure mode is by shearing in tube and hub teeth; failures occur frequently in gross tube section.



**TRIODETICS**
335 Roosevelt Ave., Ottawa 13, Ontario, Canada

*Are edge effects of great significance in hypars?* They are probably more important than in domes, but no-one really knows even with reinforced concrete hypars. In Mexico, Candela has had to post-tension hypar edges to take care of some (unknown) combinations of bending, creep and shrinkage. Space frame hypars have been built in Mexico using membrane analysis; since edge member loads are very large near supports, such elements are usually built-up sections in H or box-form and the sections that carry axial loads near supports are tapered slightly but still work well to carry bending. But to repeat, no bending theory is really available for hypars; they are being successfully designed on simple membrane theory, however.

*Is Poisson's Ratio Zero on a Two-Way Space Frame?* Depends on face diagonal system. With no face diagonals, system is like a grillage and $1^u = 0$. With face diagonals all parallel $1^u$ is again zero. With face diagonals in diamond patterns, $1^u = 0.26$.

*What aluminum alloys are favoured for space frame structures?* In Canada, 65S T6 is always used. It has good properties and low cost. Equivalent alloys in U.K., U.S.A. and Australia are designated.

*What other materials may be used?* Steel members, with various strength grades. Yield strengths of from 33 ksi to 50 ksi (14.7 to 22.3 long tons per sq in) have been used. Beyond steel, timber could be used with extruded aluminum end fittings that would provide for a connection to the wood, and could then enter the hub: these could be good for shells, but none have yet been built.

*What is the use for high tensile steel?* Steels above 50 ksi are not likely to be worthwhile for space frames, because of the effect of slenderness.

*Is aluminum preferred to steel?* More structures have been built in Triodetic in aluminum than in steel. Advantages of aluminum are appearance, lightness, freedom from maintenance. Advantages of steel are economy, high E modulus for buckling strength.

*Can square solid sections and square tubes be formed?* Any solids can be formed that are about the same thickness as the doubled wall of a circular tube of appropriate gauge. Square tubes are easily formed.

*What is the standard method of fixing timber?* A nailing strip is fastened with self tapping screws to one line of members; then the deck is nailed to this.

# FOAM SHOT ON INFLATED BAG

*About 10 years ago I had occasion to design a project utilizing inflatable structures, airhouses, at which time the simple thought occured to me that by spraying the inside surface with rigid urethane foam, these shapes would be made self supporting, insulated, and waterproof, instantly. Since then all kinds of research and patent work has been going on by me and others with their own systems and each apparently has single handedly developed something of value in dome construction. The aggregate of this work has become very significant in my opinion.*

*All that is needed to build one of these structures is an airhouse (of any shape) and the services of a foam insulation contractor for a couple of hours.*

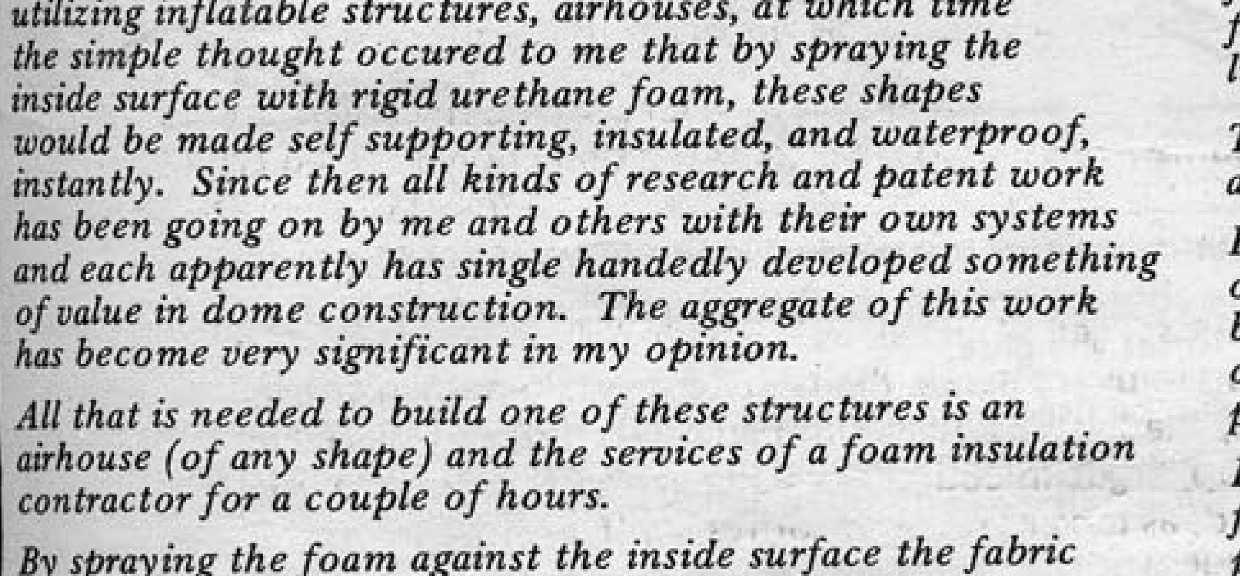
*By spraying the foam against the inside surface the fabric remains bonded on the outside of the foam shell and functions thereafter as a finished roof. Study the available airhouse material for bondability to foam. Urethane foam must be protected from the elements, including ultraviolet rays anyway and you may as well use an airhouse fabric that will bond well and remain as the finished roofing. Certain fabrics such as Ruberoid TNA bond to foam as well as qualify as Class C roofing material.*

*The airhouse can be made on the living room floor. It is taped, cemented, sewn, or heat and pressure sealed together depending on the material. It can be tailored to any shape pushed and pulled after inflation until the final form is achieved, then fixed in position with foam.*

*I have used all kinds of blowers to inflate the structures including a rented gas powered job and a squirrel cage fan from an old air conditioner which is good because it maintains a constant pressure. Use one powerful enough to stretch the fabric tightly.*

*Blow the air in through a fabric sleeve attached to both blower and airhouse. Make sure it is the same size as the blower opening.*

*There are various ways of anchoring the fabric down to some kind of foundation including these three:*




*The foam insulation contractor will charge about 12 to 15 cents per board foot per pound of density. For example a one foot by one foot by one inch deep quantity of 2 lb/cu ft foam will cost 25¢ to 30¢ in place. Foam densities vary from 1½ lb/cu ft to over 40 lb/cu ft. I have had excellent luck with a 3 lb foam recently.*

*The foam contractor should be able to do his job without a hitch if he has just a few ground rules to follow:*

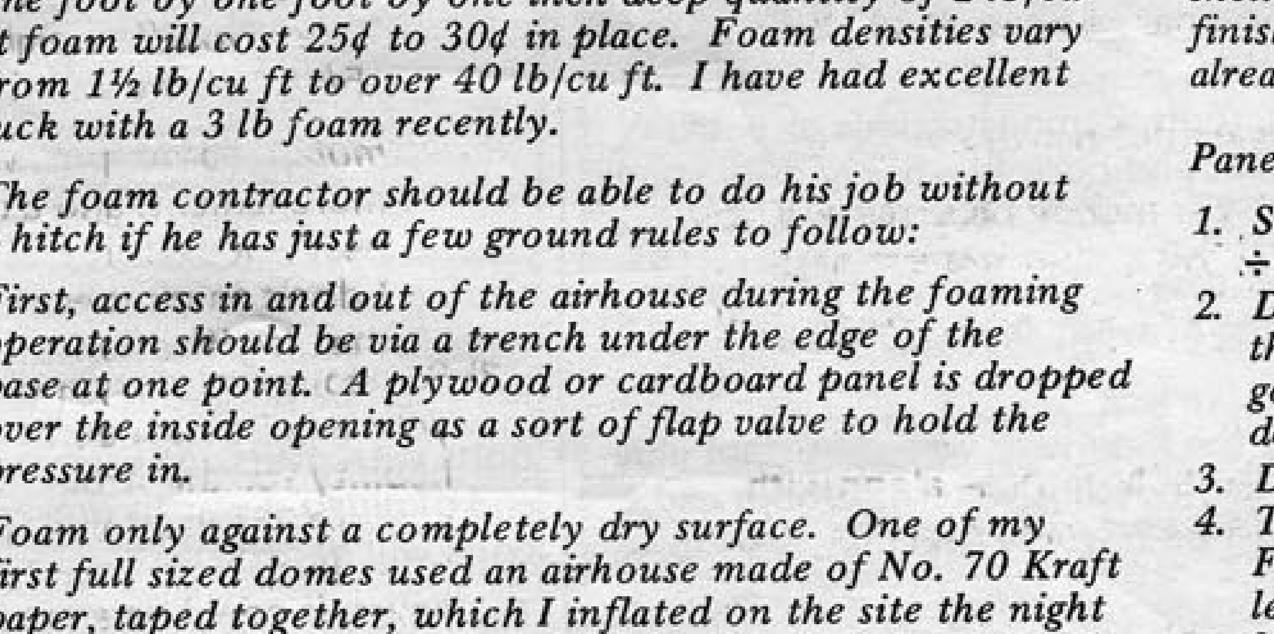
*First, access in and out of the airhouse during the foaming operation should be via a trench under the edge of the base at one point. A plywood or cardboard panel is dropped over the inside opening as a sort of flap valve to hold the pressure in.*

*Foam only against a completely dry surface. One of my first full sized domes used an airhouse made of No. 70 Kraft paper, taped together, which I inflated on the site the night before. Even though you couldn't feel it, the paper picked up moisture during the night and caused a delamination between the paper and foam. Previous to this I had experimented extensively in my lab with the paper and foam and had always found the bond to be excellent.*

*Apply the spray evenly over the entire inside surface in multiple thin layers. I mean cover the entire surface as fast as possible developing about a half inch layer per pass, as many times as it takes to build up the required thickness. This makes a stronger, more uniform shell and one that maintains the exact airhouse configuration as each pass is deposited on the already rigid form of the previous passes. The interior of any freshly applied foam section is hot and if it is applied in a thick section it wants to deform as it cools unless it has a rigid surface to hold it in position.*

*Keep the pressure on the airhouse for a full day after the foam is applied. This will give it a chance to final set against the still tight skin of the house.*

*Doors and windows can now be added. Framed doors are pour foamed into an oversized hole cut into a vertical surface. I have had good luck with the following windows and vents.*

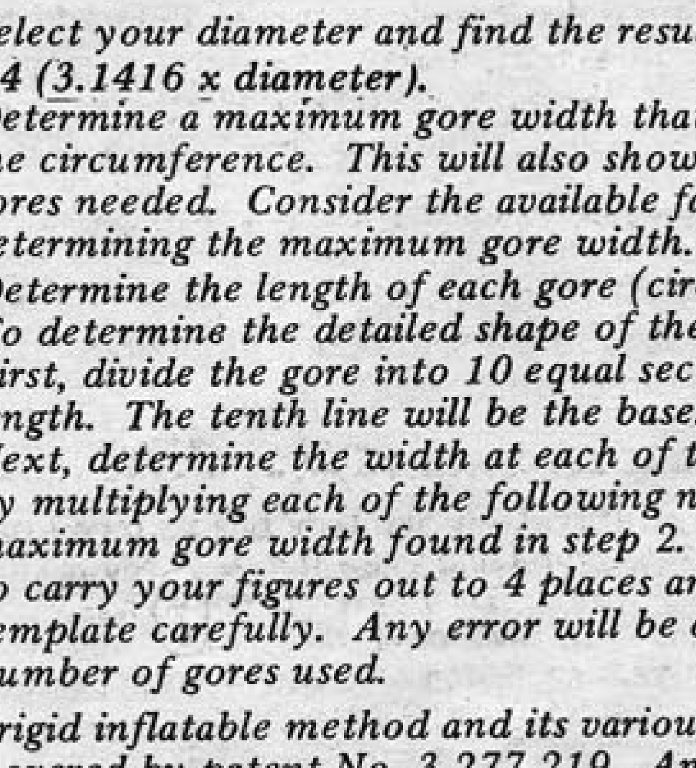



*For a stronger structure gunite or cement plaster is sprayed on over reinforcement applied to the underside of the foam shell in the areas intended for the final structure. The finished product is actually a thin shell concrete structure, already insulated and roofed.*

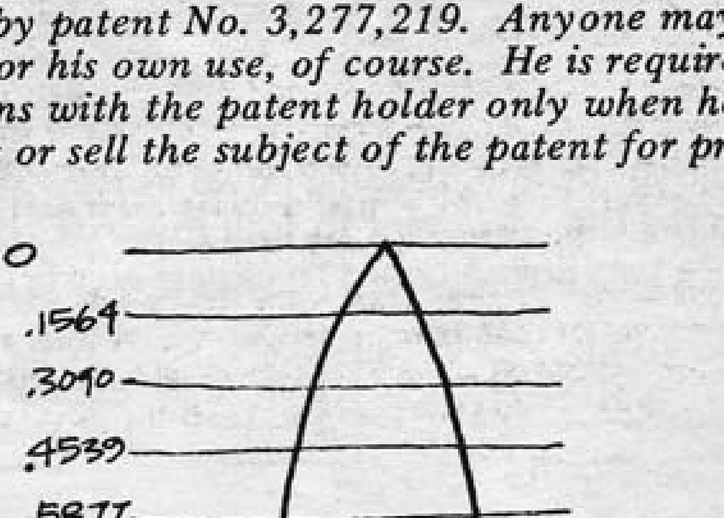
*Panel (gore) design for a hemispherical airhouse of any size:*

1. *Select your diameter and find the resulting circumference ÷ 4 (3.1416 x diameter).*
2. *Determine a maximum gore width that will go evenly into the circumference. This will also show the number of gores needed. Consider the available fabric widths when determining the maximum gore width.*
3. *Determine the length of each gore (circumference*
4. *To determine the detailed shape of the gore:*
   *First, divide the gore into 10 equal sections along its length. The tenth line will be the base.*
   *Next, determine the width at each of these division lines by multiplying each of the following numbers times the maximum gore width found in step 2. Take the trouble to carry your figures out to 4 places and lay out your template carefully. Any error will be exagerated by the number of gores used.*

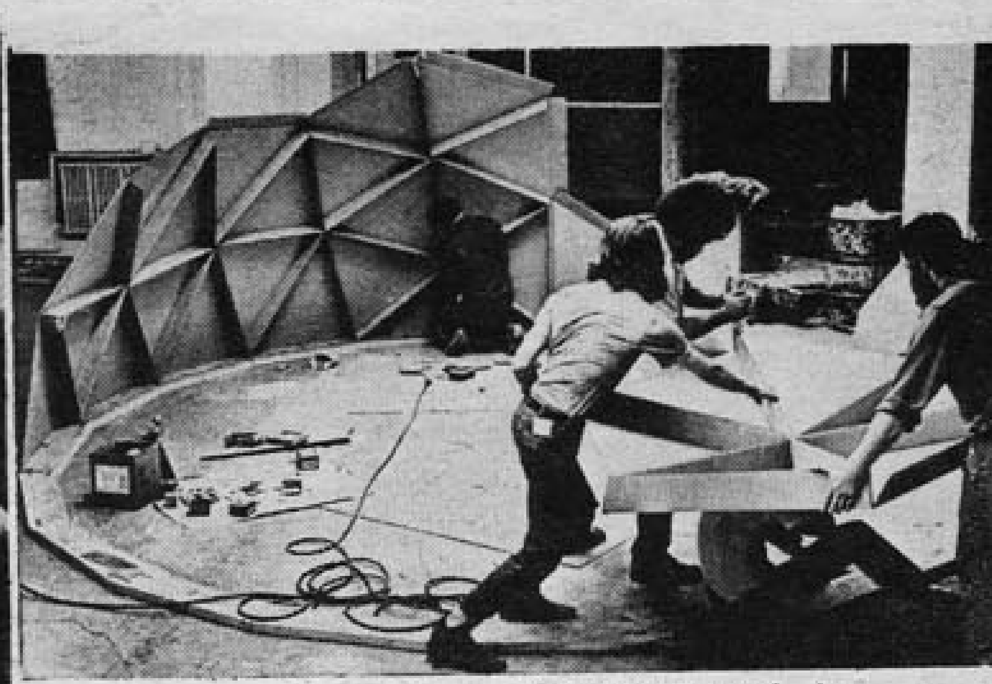
*The rigid inflatable method and its various embodiments are covered by patent No. 3,277,219. Anyone may build a structure for his own use, of course. He is required to come to terms with the patent holder only when he intends to make, use or sell the subject of the patent for profit.*

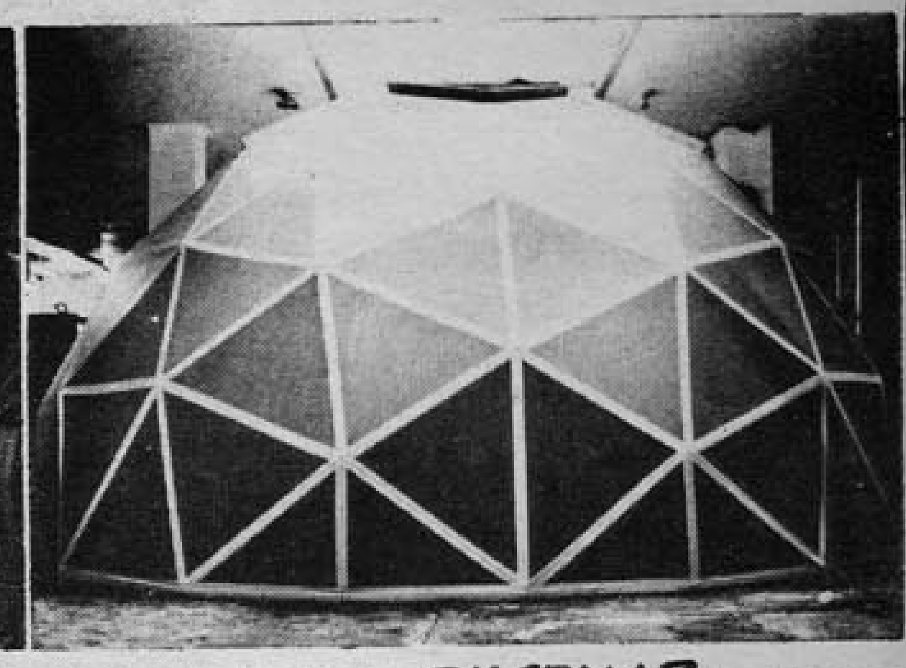


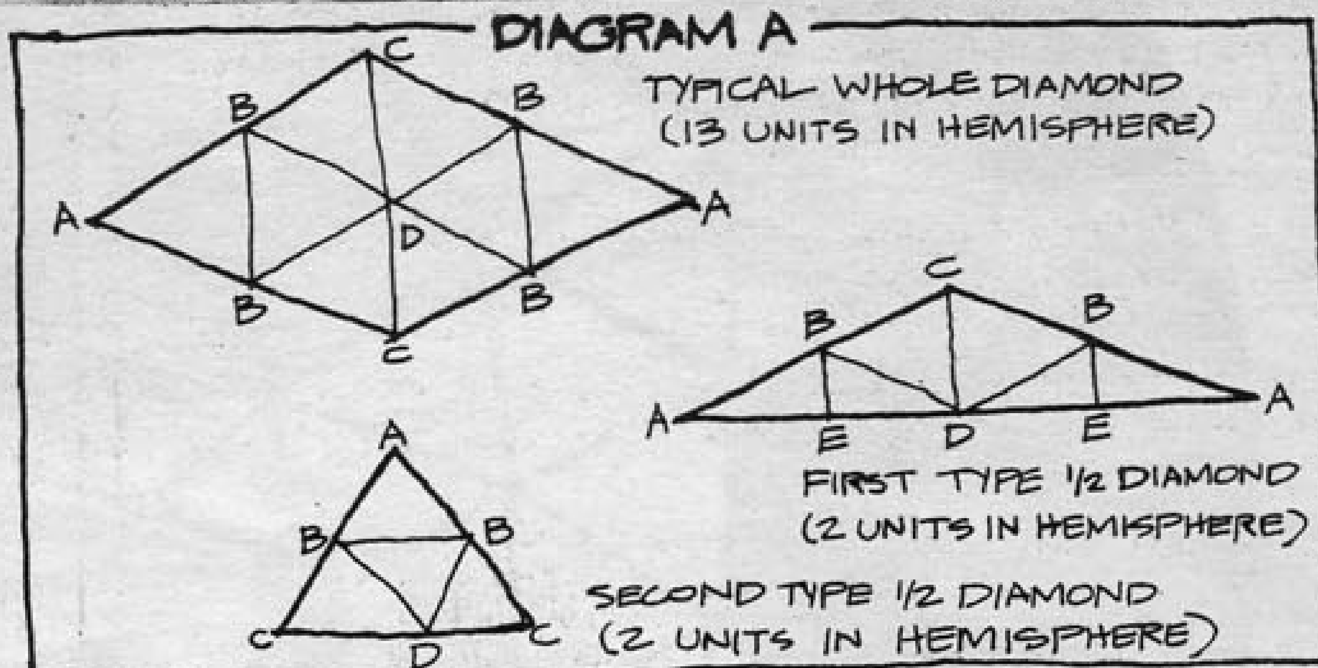

*Note: let a little extend below base*

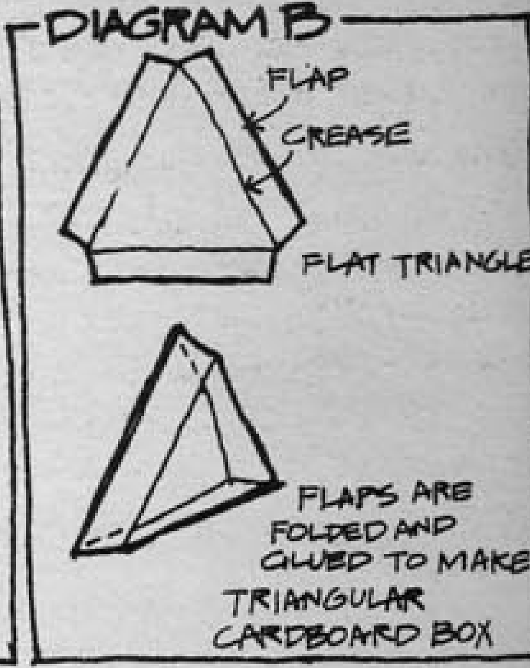


*Lloyd Turner, 15 E. Main, Los Gatos, CA 95030*








# "CHARAS"

*"Charas" was formed in September 1969 by a group of young street people from New York City's Lower East Side. Its purpose to explore the possibilities of low cost housing.*

*Shortly after our formation we asked Buckminster Fuller to help us, he then asked his assistant Michael Ben-Eli to work with us in New York. Michael devised a programme of development which has taken us from classes on geometry, structures, and geodesic domes to experiments with models and finally to the construction of a full size dome.*

*One of our models was a 5' diameter dome which was made from corrugated board scraps we found in a loft that we have. It was a 4-frequency 1/2 sphere based on the tricontehedron. It was made up of two different triangles that were assembled into 13 whole diamonds and four half diamonds as in diagram A. These sections were then assembled into the dome. We used contact cement and staples to connect the flaps. From this model we have developed a 20' diameter dome made of high performance corrugated paper board called "Dynacor". Dynacor sheets, which can take compressive loads of 1000 lbs per sq inch, were developed by Container Corporation of America in whose plant at New Jersey the triangular sections for the dome were produced. Each flat triangular section had foldable flaps which when folded produced a stiff triangular box (diagram B). Such "boxes" were then assembled together in much the same way as in the model except that in the real size structure certain triangles were omitted to form 6 windows and a large entrance door. To offset the structural effects of this omission simple wooden frames were introduced in places where such sections have been left out (see photograph).*

*The assembly was done in two primary stages. The first in which triangular sections were assembled according to patterns shown in diagram A. Here sections were glued together with sprayed contact cement. The larger sections were then bolted together with quarter inch bolts which were fitted into holes drilled along the flaps. In this way the structure could be easily taken down, moved to another site, and rapidly assembled again. Special plastic tapes were used to seal the seams. In testing at the Environmental Communications Research Center at the School of Visual Arts where we assembled the dome we found that the corrugated could be treated with polyester resin to protect it from moisture and would be suitable for a temporary outdoor structure perhaps for up to two years. We say perhaps because we have not as yet been able to test it in the outdoors; however, specifications were sent to two groups in California who have the facilities and resources to do the necessary testing.*

*Our next project will be to construct a 40 to 60' diameter dome. This dome will be a little different from contemporary domes in that it will use spherical sections instead of the usual flat ones and ferro cement will be the building material. When ready a first prototype will be erected in Woodstock, New York, where Fuller has made available temporarily a piece of land for the project.*

*Our goal is to develop a reliable and economic housing system for in and outside of the city. We are located at 303 Cherry Street, New York City, New York, 10002. If you desire information or wish to exchange information, please contact Roy Battiste at the above address.*

# WORKIN' CARDBOARD

Jay Baldwin

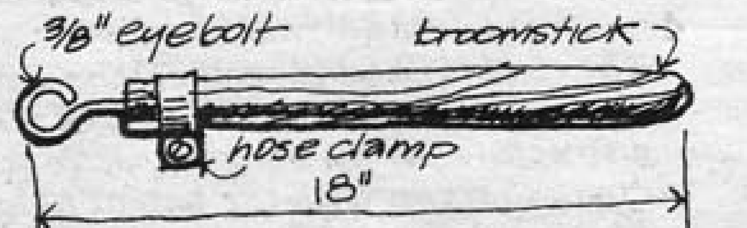
Cardboard can be worked with for less permanent structures, demonstrations or with other materials. You can use refrigerator or stove cartons and borrow a heavy duty staple gun. Waterproofing is critical.

There are two kinds of cardboard, corrugated and "beer case". The corrugated is easier to find in large pieces and is easier to work with. Use the heaviest that you can fine—at least 200 lb test.

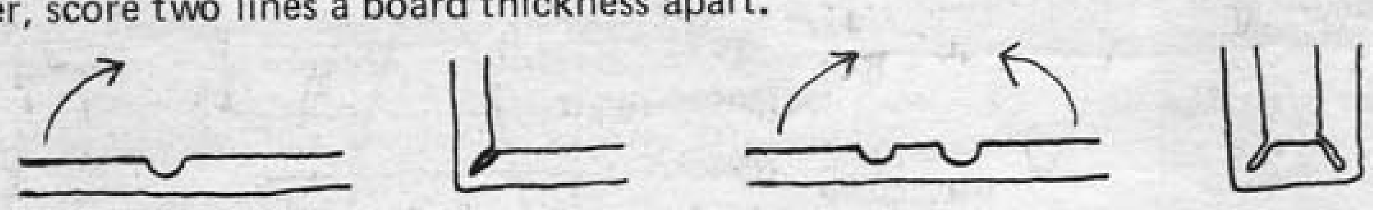
You can buy in 5 X 9 sheet for about 5¢ per sq ft. Get the kind with water-resistant glue-this will be the easiest to waterproof. The wax coated cardboard is waterproof but can't be glued or painted. Unbalanced board has heavier paper on one side and may tend to warp more in one direction.

**Cutting and Scoring**

Cardboard can be cut on a table saw or with a mat knife. Use a metal straight edge and work on scrap board to protect the blade. Curves can be cut with a bandsaw, sabersaw, or a machine called a Kutawl. You can make a tool to score cardboard for bending with an eyebolt.

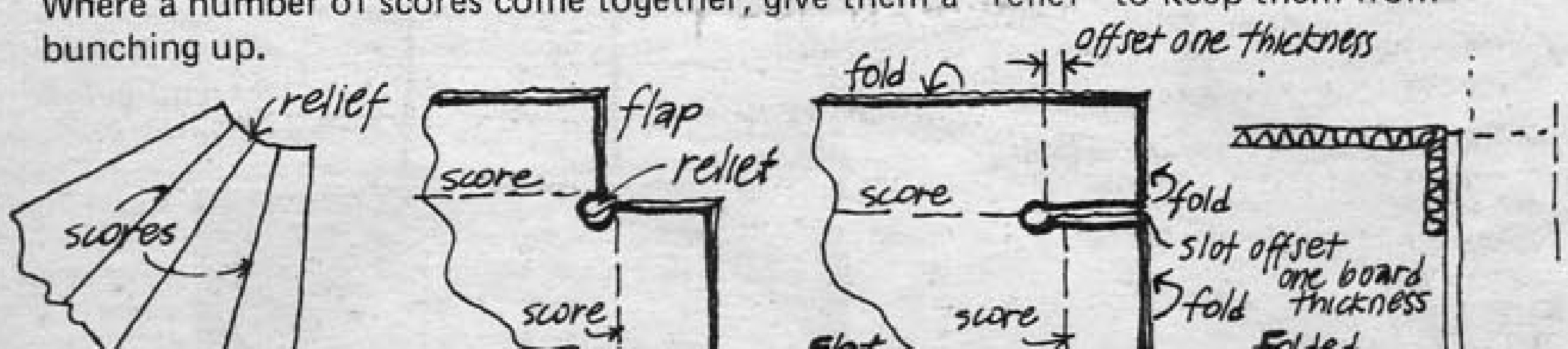



Slide it along the line, pushing down as hard as you can without breaking the board. Score on the side you want to fold *towards*. If the board has to be folded all the way over, score two lines a board thickness apart.



When laying out the pattern, remember that a score takes away board from your total. length. A 90° bend takes away ½ a board thickness. Make a test section to be sure you're going to come out right.

Where a number of scores come together, give them a "relief" to keep them from bunching up.




When flaps come together as on a box corner, be sure and allow for the thickness of the board.

Holes cut in the cardboard should have round corners to prevent stress cracks.

**Fastening**

Cardboard can be stapled, glued, taped or bolted. Make the joints so that they will be loaded in shear rather than peel.


Gluing works well—use contact cement or waterproof glue. Flaps should be at least 3" wide for good grip. If you use contact cement the flap should be made so that the joint can be pressed together to set the glue.

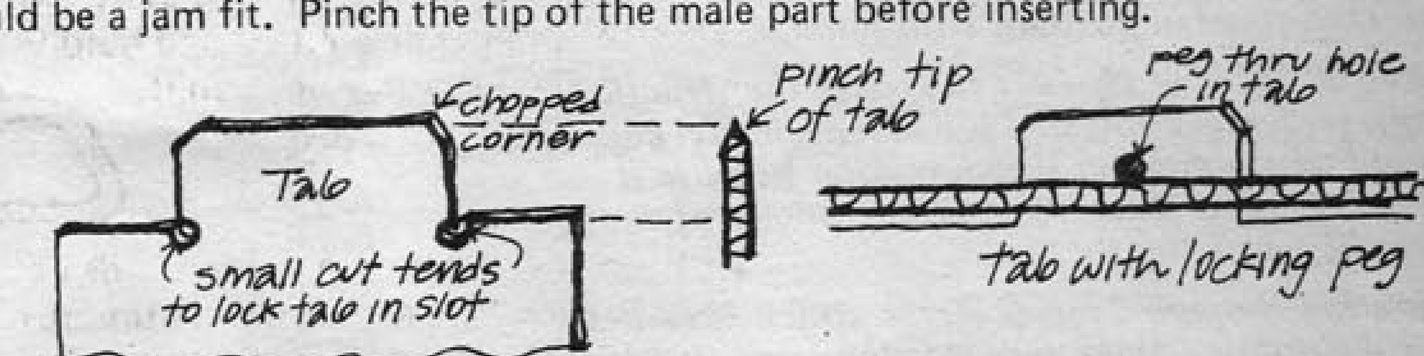
Bolts with oversized washers can be used in many cases. They are good to have at the end of glued seams to prevent the seam from opening up. The size and spacing of the bolts will depend on the loads.

Taping is for waterproofing and jobs that don't take much stress. Pressure sensitive tapes will slowly creep if under continuous load. Thermo-setting tapes don't have this problem—talk to 3M or Schjeldahl about them.

Staples can be used if the joining can be worked out to fit the gun. There is a new kind of staple that can be applied from side that might work well. Use resin, paint or tape to waterproof the holes. This Bostitch staple gun model P-6 works well.

Spur grommets can be set in cardboard to lash pieces together or to allow parts to swivel. A No. 4 grommet is a good size—the tools cost about $6, or borrow them from an awning shop.

Cardboard can be fastened with tabs. They should be as large as you can manage. The slots should be a jam fit. Pinch the tip of the male part before inserting.




**Finishing**

Before the cardboard is waterproofed the edges should be sealed. This can be done with gummed paper tape, the kind you wet. Every edge should be sealed before the parts are glued together.

After the edges are sealed, the board can be painted or resined. If you paint, use an oil based "wall sealer" or a laquer based auto primer, followed by a finishing coat. Use lots of paint on the cracks and edges.

**Domes**

Cardboard domes can be made in the same way the aluminum triacon or the aluminum sun dome were done. Or triangular sections can be folded into the edges of the panels like the Charas dome. Fuller's Laminar Geodesic was designed to be built out of FomeCor, but could just as easily be built out of cardboard.

FomeCor and steel board are two new kinds of sheet material that can be used in similar ways to cardboard—see the Materials page.


# Costs

Domes are being built in the country because there's no freedom in the cities. Bankers, unions, contractors, building materials dealers, building inspectors, architects, engineers work smoothly together to protect their personal interests. Take banks for example:

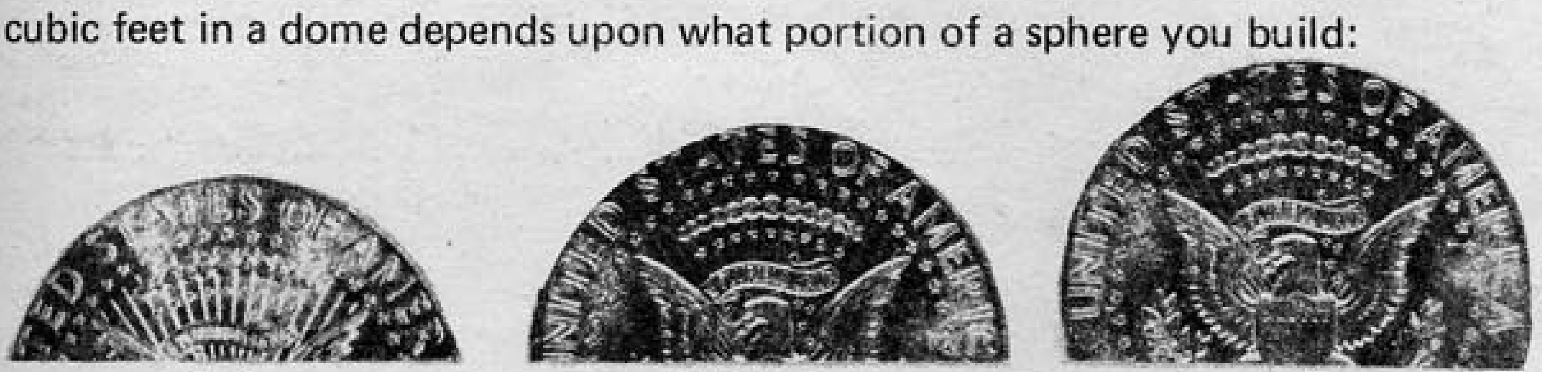
A home mortgage more than *doubles* the cost of a building. If you borrow $15,000 at the current 7½% rate of interest, your monthly payments are $104.88 for 30 years. Sounds reasonable, but when you do some multiplication, you find out that at the end of the loan period you'll have paid the bank $37,756.80 for having borrowed $15,000.

The bank, for handling papers, collects $22,000.

So, bypass banks. Then, if you provide your own labor, you'll save another 50%. And if you can utilize scrap materials, or a lesser amount of materials because you're structurally more efficient, you may reduce the cost of your shelter to ¼ of ordinary costs.

Costs per square foot are deceptive, especially since in domes you usually build lofts, and are not confined to the floor. Costs per cubic foot are a far better measure of value.

Total cubic feet in a dome depends upon what portion of a sphere you build:



3/8 hemisphere 5/8

Here is the cost of the Pacific Dome, as described on pp. 20-24, just the shell, no plumbing or wiring or interior work. However, people writing in are building domes of this size for considerably less now.

**Pacific Dome**

24' diameter 5/8 sphere plywood dome
Floor area: 452 sq ft
Volume: about 4500 cubic ft

| | |
|---|---|
| Floor | |
| frame | $110.00 |
| plywood | 124.00 |
| Floor cost | $234.00 |
| struts: total about 800 lin ft @ $380/1000 Bd. ft | 160.00 |
| plywood: total about 30 sheets @ $8 | 240.00 |
| nails | 25.00 |
| hubs | 15.00 |
| straps, buckles | 35.00 |
| vinyl | 20.00 |
| caulk | 35.00 |
| paint | 25.00 |
| wood for window batts | 20.00 |
| misc. | 30.00 |
| insulation | 90.00 |
| Total cost | $929.00 |

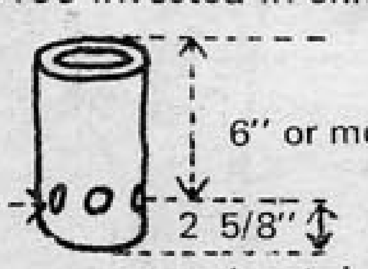
# Masts

If you're going to be climbing on a dome, it's helpful to have a mast.

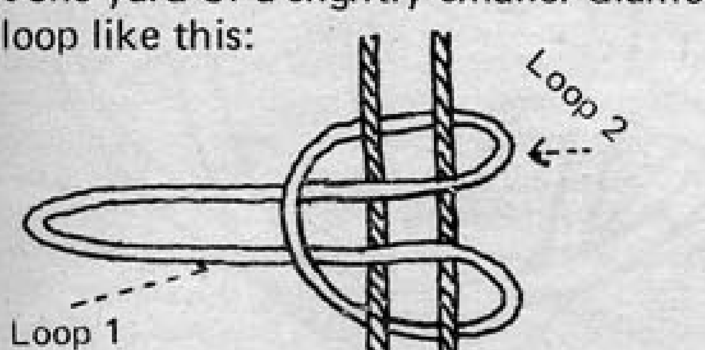
The mast goes at top center, projects 6" or more above the dome, and gives you something to throw a rope over when climbing on the exterior (which will be often).

Bill Woods taught us this method. He has $100 invested in climbing equipment—it's a long way down.

We made our masts like this:

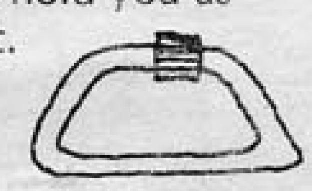



The *6" or more* part is what you throw the rope over. Look in mountain climbing catalogs for the equipment: a good 1/2" nylon rope—Goldline is o.k.; Edelreid Perlon is better. About one yard of a slightly smaller diameter rope (or nylon strap). Tie ends together to form loop like this:

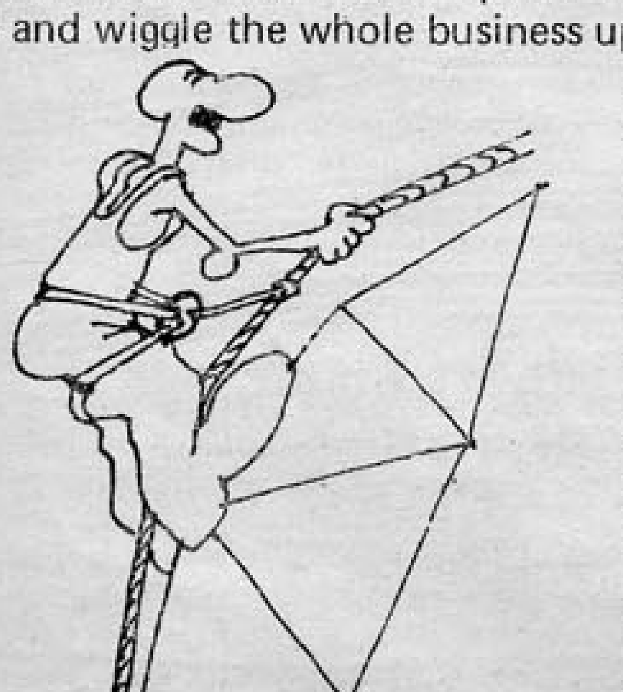



It's best to take loop one around again and come through loop two again—for double protection. This knot will slide when no pressure (weight) is placed on it, but will tighten, and hold you as soon as you put your weight on it.

Carabinier with safety lock:



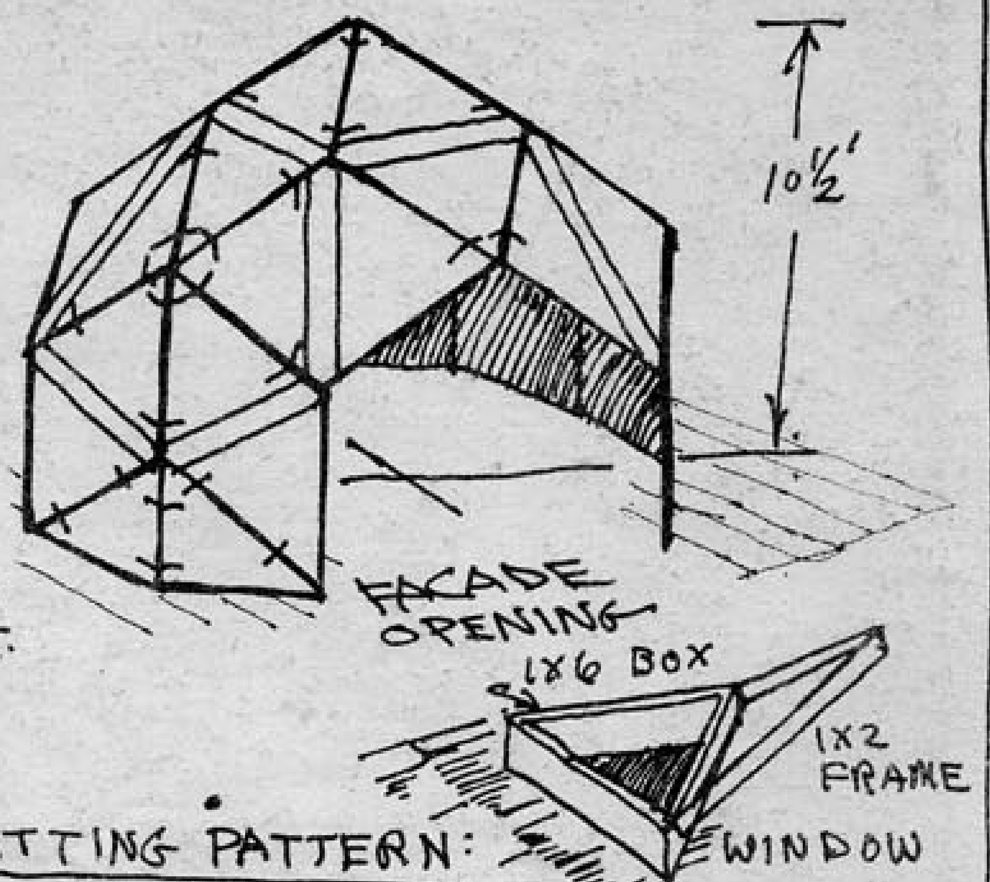
Harness: You can buy a ready-made harness or make one out of about two yards of nylon strap from a mountain climbing shop. The ends are tied to make a continuous loop. To get into it, hold the entire loop horizontally behind your ass and bring the loop ends together in front of your crotch. Hold them with one hand and reach back between your legs with your other hand to grab the lower line. Pull this line between your legs to meet with the other loops in front. Hook the carabinier through all three loops and wiggle the whole business up to waist level.



When you lean back, the knot holds. To move, you take weight off the knot. When you get to desired position, lean back, and you can work with both hands free. It's a strange sensation—you'll gradually learn to trust the rig. It works best to start at top, and work your way down: you get so you learn the amount of relief needed to descend, and soon you're walking up and down on the domeskin. Have care not to slip feet up-head down; you'll fall out of the harness.

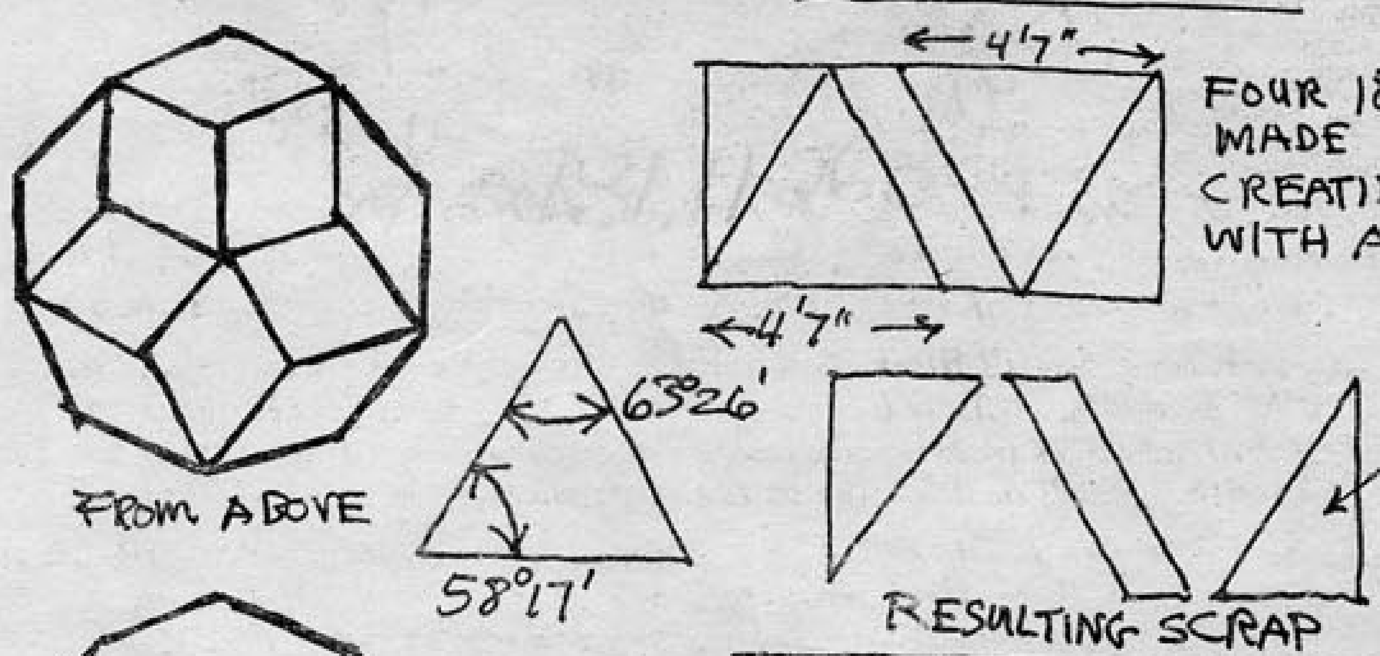
## TRIACONTAHEDRON

A SKIN SUPPORTED PLYWOOD DOME SUGGESTED FOR LAMA BY STEVE BAER



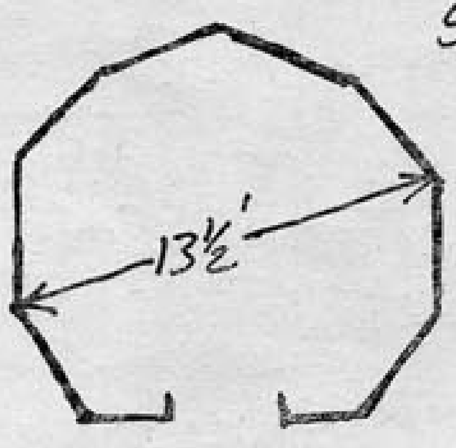

THIS STRUCTURE IS ADEQUATE FOR TWO PEOPLE WHO ARE INTO MINIMAL SPACE REQUIREMENT. CAN BE JOINED AT FACADE OPENINGS TO FORM DOUBLE OR TRIPLE UNITS.

CUTTING PATTERN:



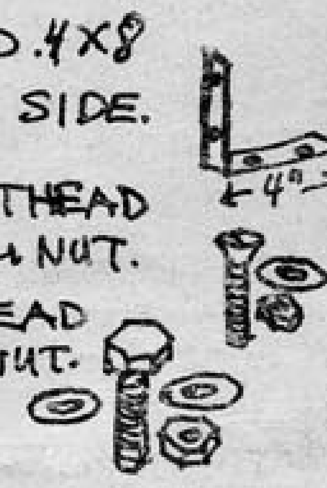

FOUR 18° CUTS ARE MADE IN EACH SHEET CREATING 36 TRIANGLES WITH A 4'7" BASE.

TRIANGLE SCRAP IS USED TO FILL IN BOTTOM OF DOME WALLS.



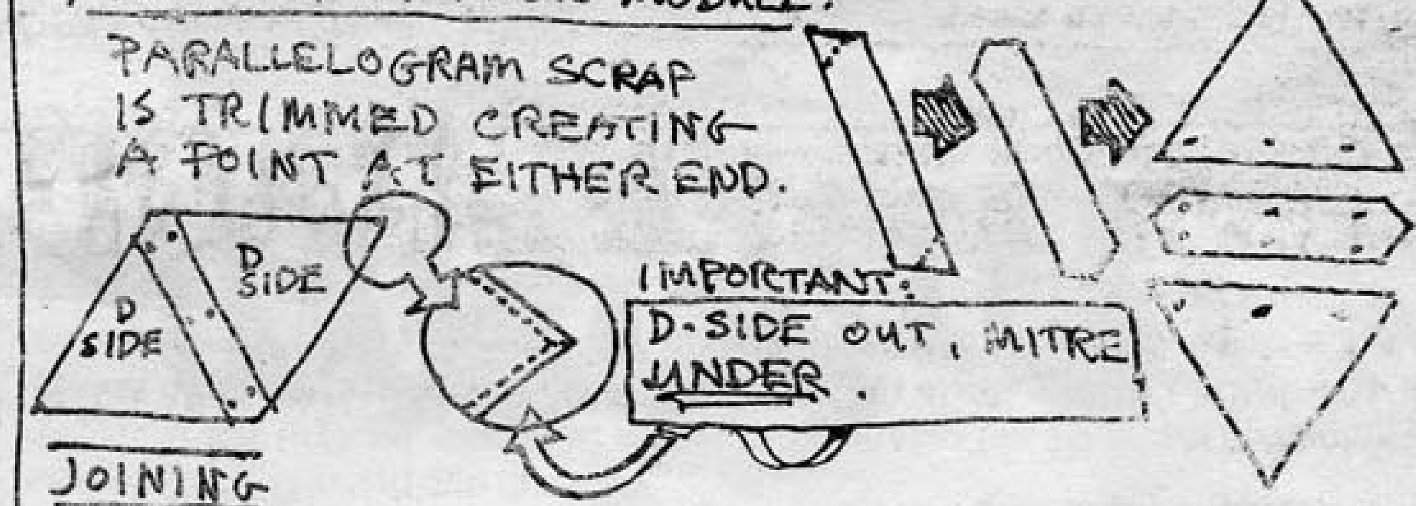

MATERIALS FOR BASIC SHELL:

18 SHEETS 5/8" AD PLYWOOD 4X8
120 ANGLE IRONS 4" TO A SIDE.
440 STOVE BOLTS 1/8" X 1" FLATHEAD SLOTTED WITH WASHER & NUT.
108 CARRIAGE BOLTS HEX-HEAD WITH TWO WASHERS & NUT.



ASSEMBLY OF BASIC MODULE:

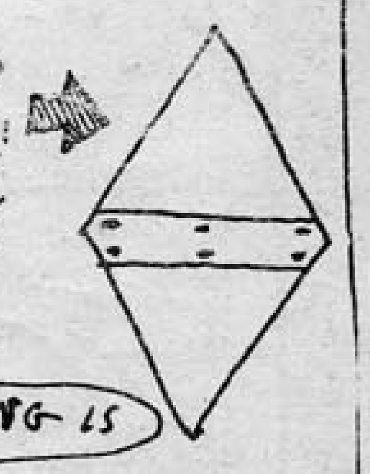
PARALLELOGRAM SCRAP IS TRIMMED CREATING A POINT AT EITHER END.



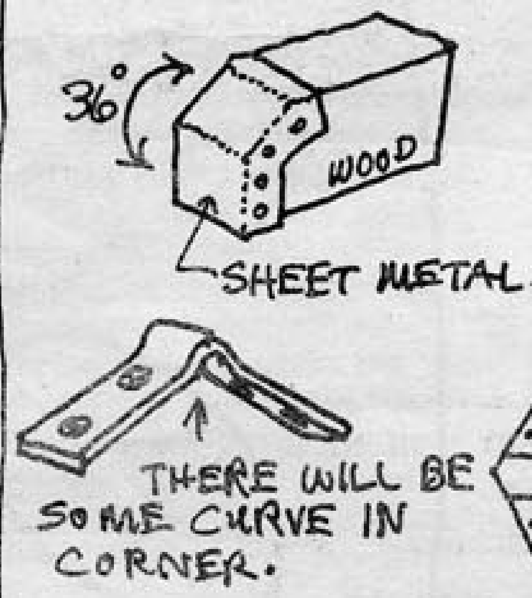

JOINING

3 ANGLE IRONS ARE USED PER EDGE. MAKE A DIE FROM A 4X6 BLOCK CUT AT THE BREAKING ANGLE OF 36°. ANGLE IRONS ARE BEATEN AGAINST THIS FORM—SPREADING THEM TO 36° SOME WILL BREAK. MOST WILL RESULT IN A USABLE JOINER.

TRIANGLES & SCRAP ARE PRE-DRILLED, THEN JOINED BASE TO BASE. PLENTY OF GLUE. SIX CARRIAGE BOLTS PER UNIT.



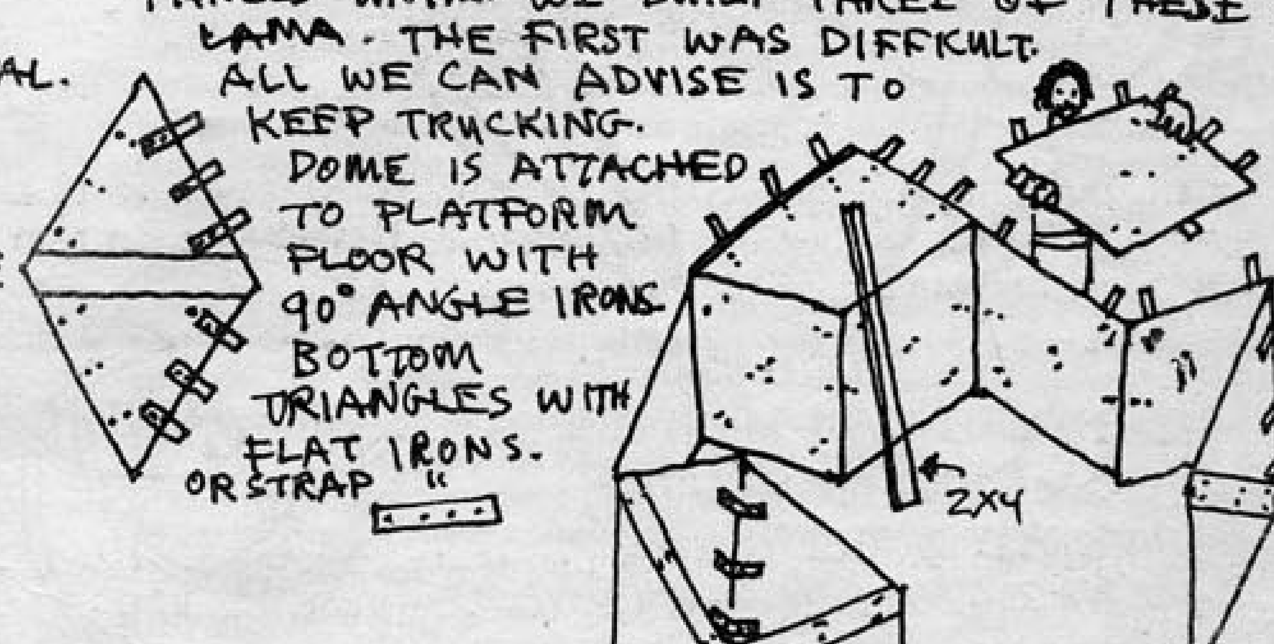
ACCURACY IN DRILLING IS A MUST




THERE WILL BE SOME CURVE IN CORNER.

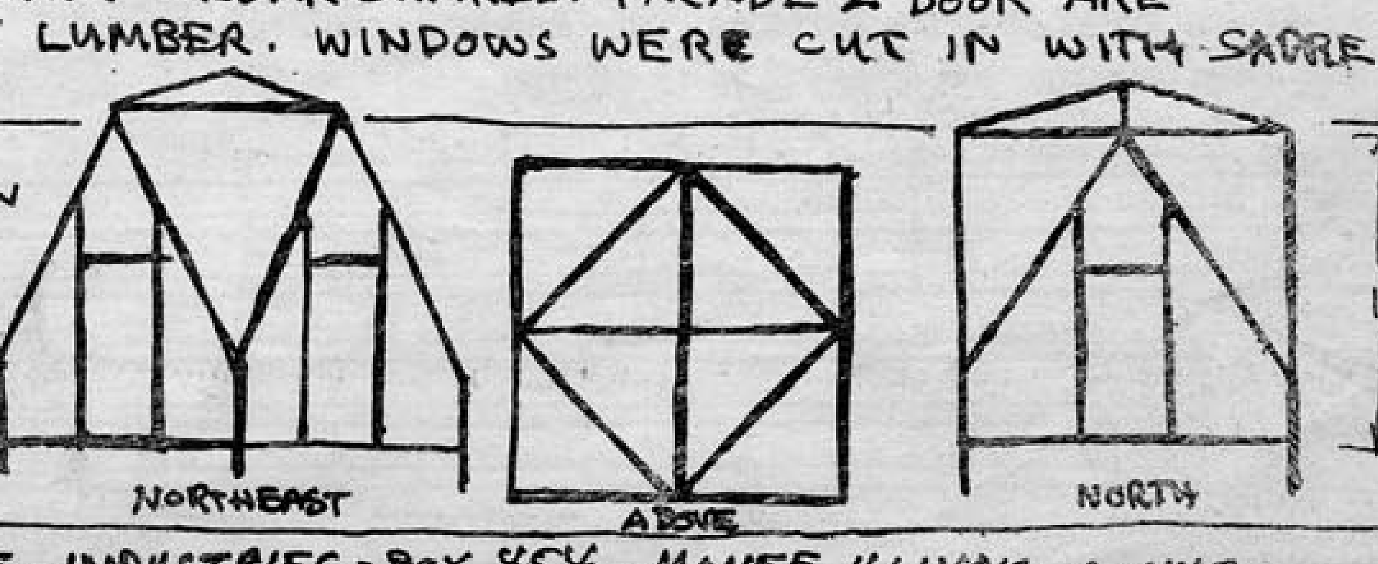
PANELS ARE PRE DRILLED, JOINERS ARE ATTACHED TO ONE SIDE OF EACH TO FACILITATE CONSTRUCTION. 2X4 CAN BE USED TO PROP UPPER PANELS UNTIL. WE BUILT THREE OF THESE AT LAMA. THE FIRST WAS DIFFICULT. ALL WE CAN ADVISE IS TO KEEP TRUCKING.

DOME IS ATTACHED TO PLATFORM FLOOR WITH 90° ANGLE IRONS. BOTTOM TRIANGLES WITH FLAT IRONS. OR STRAP




FINISHING: WE COVERED ENTIRE SURFACE WITH BLACK FELT. TACKED ON 1X2 FIRING EVERY 16" FOR SUPPORTING CEDAR SHAKES. FACADE & DOOR ARE ROUGH CUT LUMBER. WINDOWS WERE CUT IN WITH SABRE SAW.

ALSO, A CUBEOCTAHEDRON SEND TO HOME INDS. FOR INFO ON BOTH THE TRIA AND CUBO



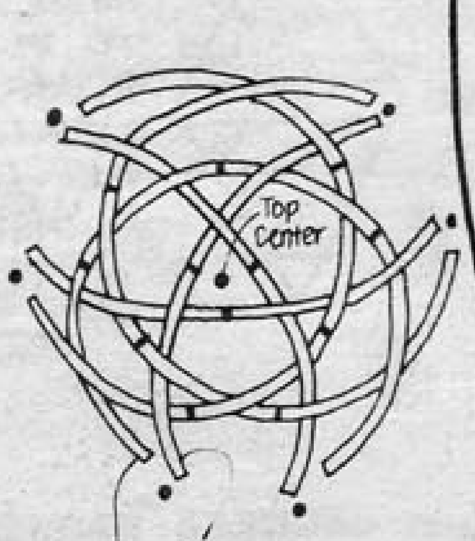

HOME INDUSTRIES: BOX 454, MONEE, ILLINOIS 60449

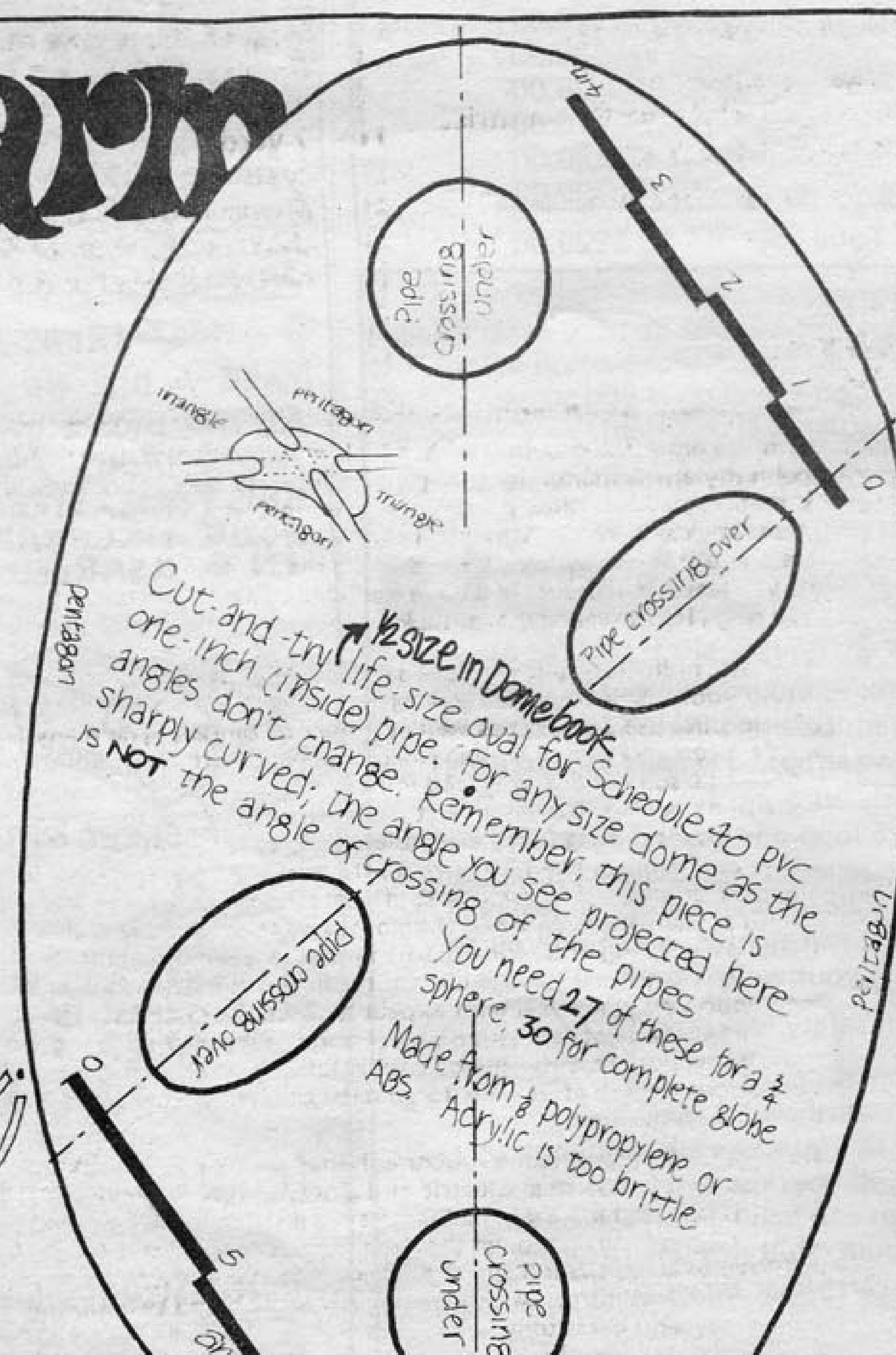
*AIR BUILDING*
*Air building by Ant Farm, made for Mt. Fuji Rock Festival, which never happened.*
*Ant Farm, 247 Gate Five Rd., Sausalito, California 94965.*

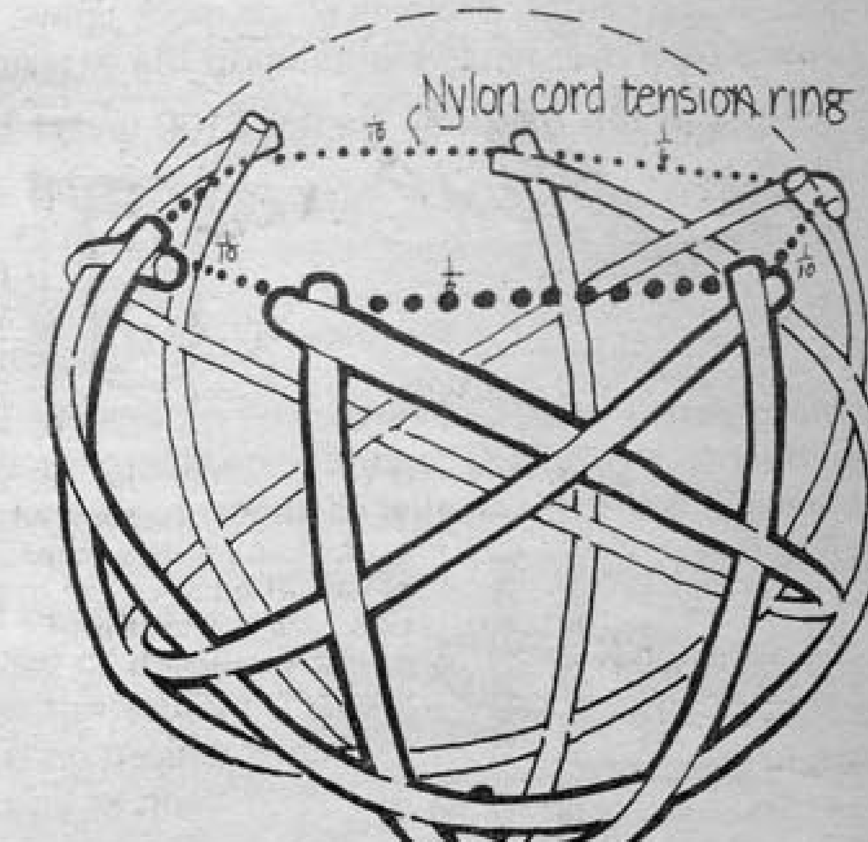
# antfarm

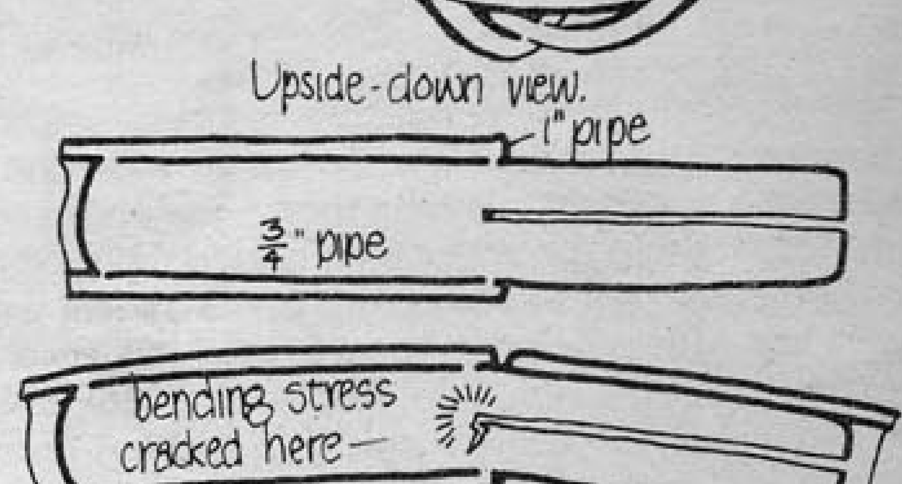
*The Ant Farm is into air buildings, tent domes, nomadic visions, video They have published an instruction booklet on air buildings called the* Inflato Cookbook, *$3.00 from the above address.*


This 3/4 sphere pattern is usable in functions where height rather than floor area is needed, like darkrooms. The distance between each intersection of pipe is a constant, 1/10 the circumference. This one was made in six pieces of pipe, cut from 8-20ft lengths and joined so that joints would occur at midspan & not at intersections. Using long pipes is unweildy. We wont do it that way again unless the pipe is inflated, roll-up tubing.



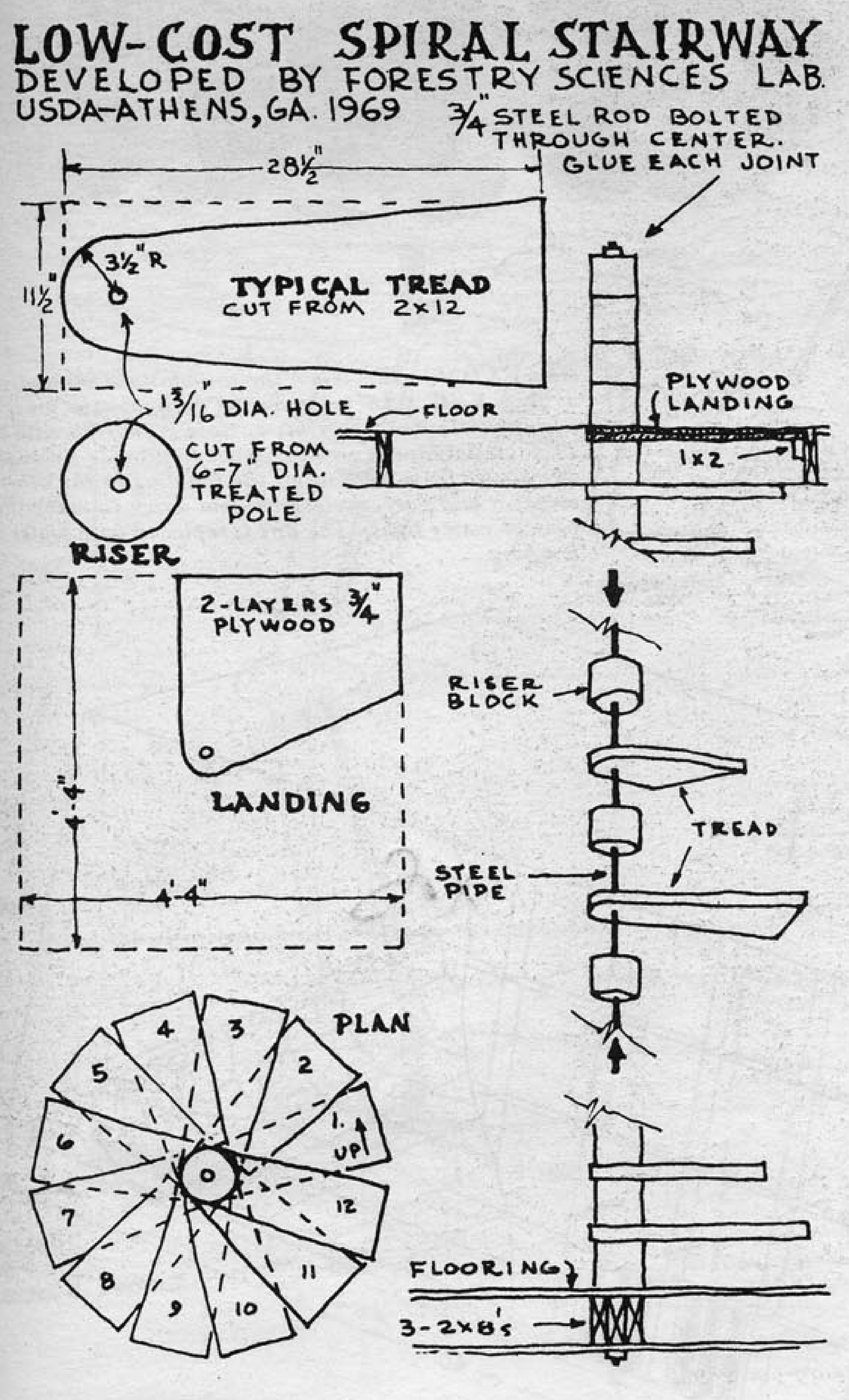





We used big ovals of flexible plastic to anchor each intersection of pipe. They must be slipped over the ends of the pipe pieces as they are assembled. It takes at least five people, at the points shown in the diagram at left, to draw the top up and the ends in to a dome shape. The rope ring is approximately $\frac{3}{6}+\frac{3}{10}=\frac{8}{10}$ of a circumference. We have allowed more, splaying the dome a bit for stability.

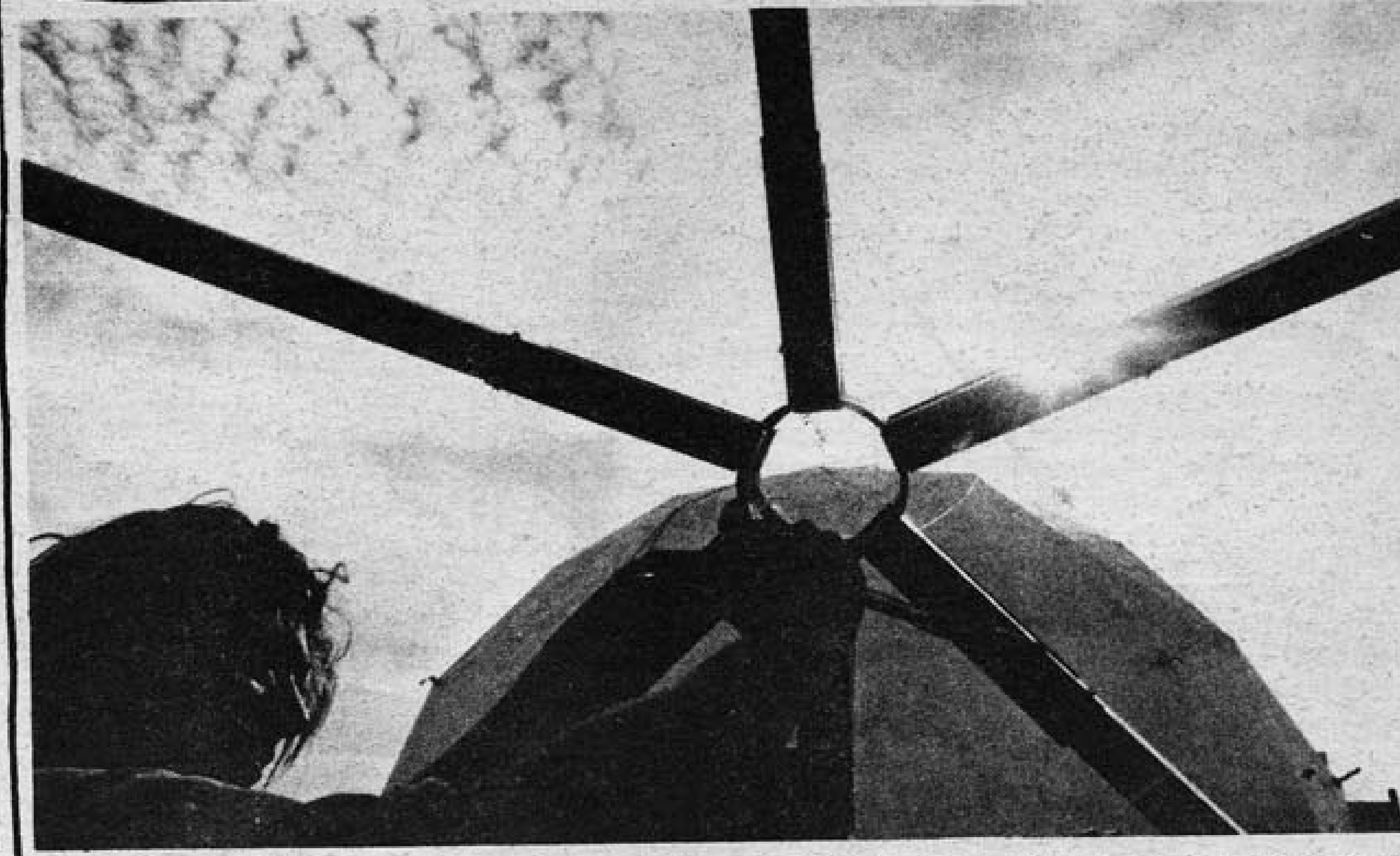



Ken Kern's *The Owner Built Home* is the best building manual available today.

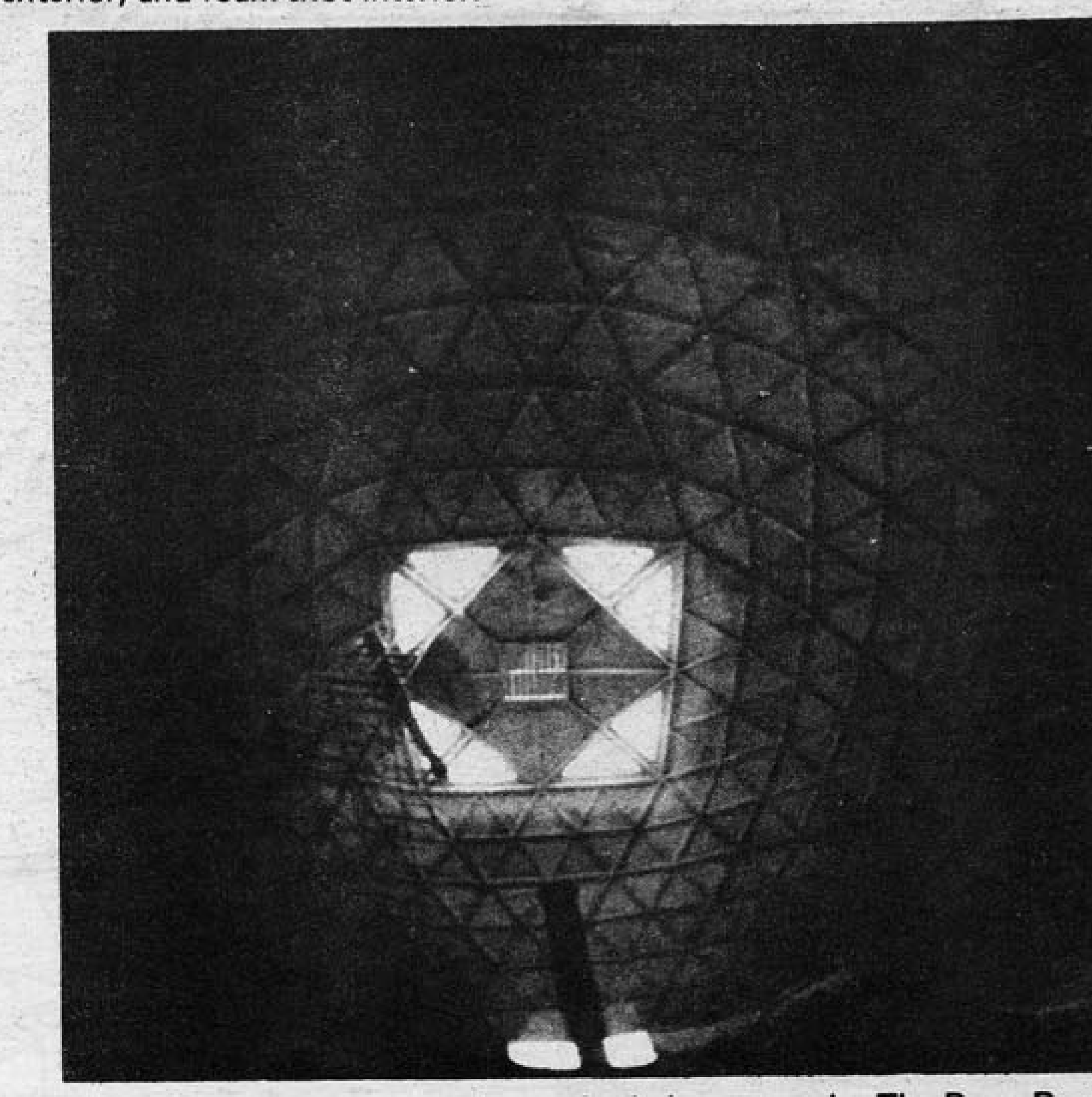
It contains information you'll not find anywhere else. There are low-cost building techniques from underdeveloped countries that can't afford U.S.-style waste, countries that have of necessity developed building techniques for housing the poor.

The book is oriented at designing and building your own home, and not borrowing money from banks to do so.

*The Owner Built Home* by Ken Kern.
Specialty Printing Co., Yellow Springs, Ohio. Available from Ken Kern, Sierra Route, Oakhurst, California 93644



Dyna Domes produces plywood domes—2 X 4 struts, plywood skin, fiberglassed exterior, and foam-shot interior.



Most of the people that buy these domes do their own work. The Dyna Dome kit sells for about $2 per sq ft of floor space; this is just the shell and doesn't include the floor, wiring, or plumbing. The 26' dome is $1200, ready to erect. The concrete floor—about 7 yards of concrete—is about $100. With plumbing wiring and owner labor the dome costs about $1600-1800, most Dyna Dome owners haven't had to borrow from banks. Members of a Baptist Church in Phoenix built a 60' dome church (with gold flecked paint on the interior struts) at a cost of about $6 per sq ft, furnished. The pastor broke his leg helping build the church.

Dyna Domes
22226 N. 23rd Ave.
Phoenix, Arizona 85027

# Joining

Nails, screws, and bolts have been around for a long time, and with good reason. They are cheap. But there are many new adhesives and lesser known joining methods that supercede the mundane nail on a more interesting level. They make possible inconceivable constructions...

In general, look into epoxies when you want to join materials with impermeable surfaces (like metals) in an extremely strong somewhat brittle monolithic bond. It bonds well to almost anything except "greasy" plastics. Relatively little epoxy resin will bind a great deal of filler similar to the material you are bonding, so monoliths of similar expansion and contraction are possible even though the pieces do not fit well and voids are filled with the epoxy filler mix. It is much like cement in that it holds by solidifying in an almost irreversible chemical reaction, but epoxy holds better and accepts a much wider variety of "aggregates". One of the broadest lines of epoxies, including fast and slow hardeners, flexiblizers, and many fillers that is obtainable without a fancy letterhead is put out by Devcon Corp. (Danvers, Mass.).

Convenience clamping with epoxy that sets in 3 minutes is a reality, but a high cost, and unbelievable exotherm (gives off a lot of heat as it sets, making thick sections break apart). Convenience mixing in the field is provided by pre-measured squeeze Bipax put out in some 40 different epoxy formulations by Tra-Con, Inc. (55 North St., Medford, Mass. 02155). Approximate costs for roughly 2, 10, and 30 gram Bipax are $.75, $1.10, and $1.70; with a $9.00 per order minimum. They even have one claimed to form strong bonds with wet wood. Dry wood rot can be prepared for resurfacing with a penetrating epoxy available at Sears. Fiberglass freaks can work on styro-foam, redwood, metals and close-grained hardwood with epoxy resin available at Sears and Wards. While the epoxy resin has better abrasion and impact resistance than the usual polyester fiberglassing resin, its cost is roughly double ($20 v. $10 per gallon in small quantities)...

You can also do interesting things with substances that harden by freezing. Welding metals and plastics by direct heat, allowing the melted materials to flow together and freeze solid, is common enough. They also can be welded by indirect heat, caused by rubbing their molecules together with microwave or ultrasonic sound (or more exoterically by high energy dielectric fields and induction). It is particularly good for difficult to join plastics like polyesters (Mylar). Should UV resistant Mylar return, you can get air tight pillows cheaply made by the nearest blood plasma bag fabricator. Direct or indirect heat welding does not help you in joining materials, like wood, that are very difficult to melt.

Here we enter the province of hot melt glues. A thermoplastic like polyethylene is melted in an applicator, spread between 2 hunks of something, which when pressed together cool the hot melt, freezes it and makes it meld. Almost all cardboard cartons are made this way, and it is widely used for attaching shoe soles. The hot melts stay somewhat flexible, and have the high initial tackiness and quick freezing (10-60 seconds) that make it ideal for quick mock-ups...

The last traditional field of glues are those that harden by solvent evaporation. Solvent welding of plastics is common, many commercial plastic glues use a solvent as well as a filler or binder. The many contact cements use predrying periods to cope with the problem of getting the solvent out of closed joints. The sandwich trick, using something porous like wood that will eventually allow the solvent to escape makes joining 2 impenetrable membranes like metal or Mylar possible. Porous materials can store the evaporated solvent, be it aromatic or water, and allow it to migrate back and weaken the joint. This is particularly true when the porous material is immediately sealed by painting or coating before all solvents are driven off by heat. If no unsealed surface is open to the air, the stored solvents may undo you when you least expect it. Most solvent based glues and contact cements are commonly known. One surprisingly good popular product recently introduced is Elmer's clear contact cement which does the job after only 15 seconds predrying time instead of the usual 15 minutes...

The most common silicone rubber adhesive, a one-part thixotropic paste put out by General Electric and Dow, can get remarkable results if fully cured. Wait 10-30 days for a full cure of thin layers up to about ¼", even though the tube suggests a shorter time. You will have to go to the industrial products to get a two-part system for very thick sections. Although not a solvent based system, the one-part system cures only when the acetic acid gets out and moisture gets in. The optimum cure with the usual hardware store bought product is at 90°F and 90% humidity. If you can wait for the full cure time, this common stuff works well as the permanent adhesive for parts held by the before-mentioned tacking adhesives. Prices are high, so look for products from small companies (e. g. Devcon) that are just coming out. For some reason, standard caulking tubes of the G. E.'s hardware store variety sealant is cheaper from a semi wholesaler like Silvo Hardware (107-109 Walnut St., Philadelphia, Pa. 19106) in lots of 5 tubes than is the apparently similar industrial product bought directly from G. E. in lots of more than 480 tubes.

Some more traditional methods of joining sometimes overlooked: Rivets, explosive rivets that need no more than the heat of a soldering gun or torch to make good tight seals even in blind holes and are cheap and quick. One source: Palley's (2263 E. Vernon Ave., L. A., Calif. 90058) supplies 500 Dupont explosive rivets as mix 19 for $2.95. Drive rivets available from Southco (Lester, Penn. 19113) are set with only a hammer and are removable. Available in aluminum, steel, and high impact nylon, they are set blind without any special tools through 2 pieces of metal or to attach metal to wood. After the holes are drilled, drive rivets are put in hole and set by hammering down the center pin. To remove, drive the pin all the way through. Self-tapping *and* drilling screws for both metal and plastic are available from Elco Industries, Inc. (1111 Samuelson Rd., Rockford, Ill. 61101). Any heavy duty drill will start these through even ¼" plate steel without even a center punch needed. The drill screw for plastic works without splitting the plastic. Steel strapping for crates takes special equipment, a cehap replacement is Avistrap nylon cord strapping (American Viscose Division, FMC Corp., Phila., 3 Pa.). A bit rough on the hands, but all you need are their cheap bent wire buckles and you can bail up tons of books for moving without boxes. No idea of how it weathers, but could be used as a throw away band clamp. Monumental structures could be made with hooping and cooping. End grain plywood joints have always been troublesome. Tite Joint fasteners made by Knape and Vogt (Grand Rapids 4, Michigan) uses a sort of internal turnbuckle arrangement for good but relatively expensive solution (50¢ ea).

There is a certain fascination with the newest products and the most elegant solution that obscures, sometimes, the cheap and simple. For example, water pipes and their fittings can be used as super-strong long bolts and can be bought used. C & S Domes (1000 Alba Rd., Ben Lomon, Ca. 95005) with Jim Passage is currently developing a support system using close pipe nipples and flanges as bolts between dome sections. These hollow "bolts", in turn become bushings for a stressed wire cable lacing...

REFERENCES

*Structural Adhesives and Sealants*—an excellent introduction in the form of a reprint of some 17 articles that appeared in "Product Engineering" magazine, $3 postpaid from: Reprint Dept., Prod. Engineering, 330 West 42nd St., N.Y., N.Y. 10036. Ask for No. R115.

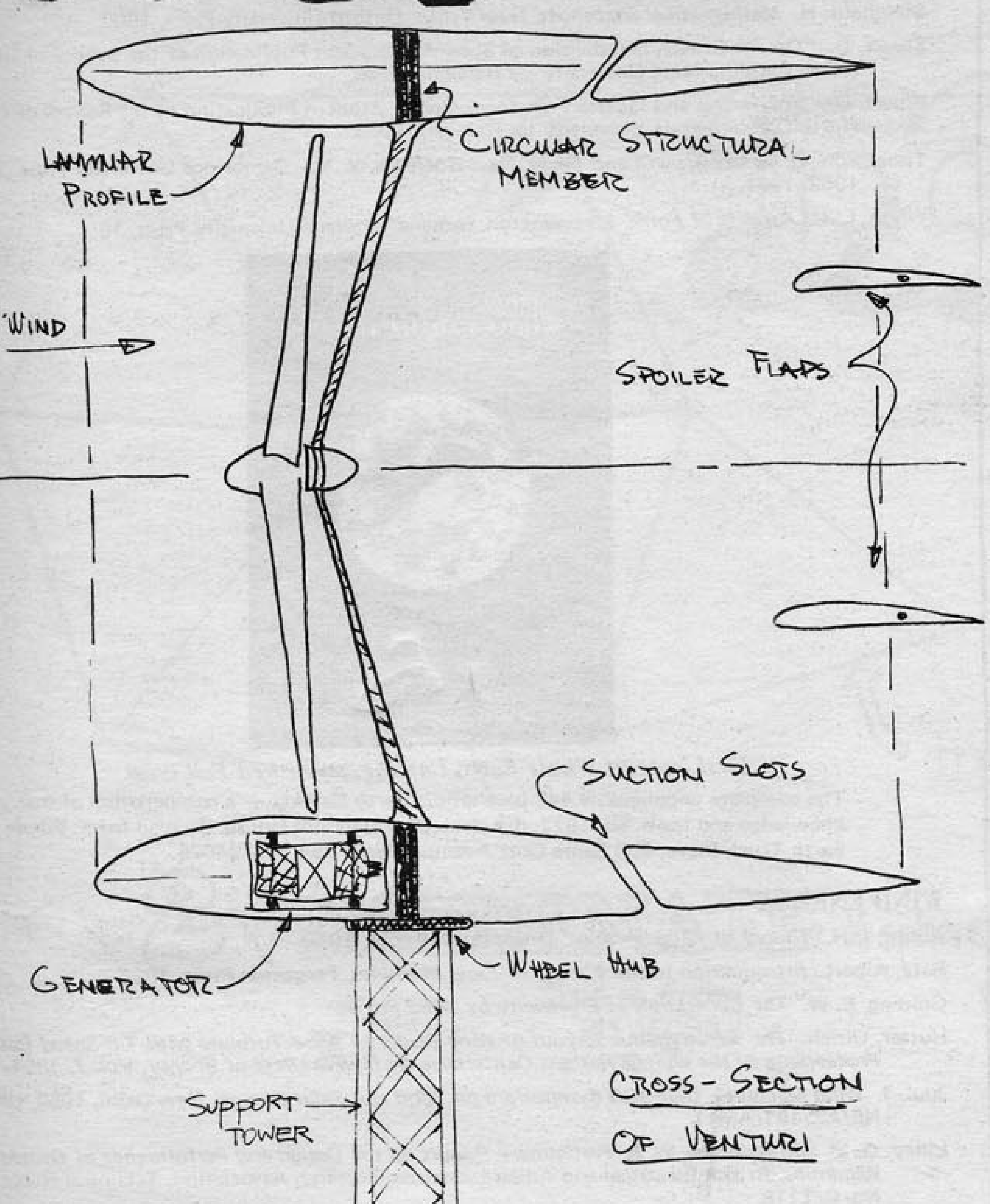
*Handbook of Adhesives*—Irving Skeist, Ed., Reinhold, 1962, $23.50.

"Modern Packaging" Magazine, Encyclopedia Issue, July 1970. $10 including a 1-year subscription from Box 430, Hightstown, N. J. 08520. Section on adhesives, p. 108 et seq.; section on Hot Melts, p. 574 et seq. Has just about the only current information on hot melt glues and applicators.

"Structural Adhesives" (pamphlet) and "Guide to Plastics Bonding" (pamphlet marked: "CONFIDENTIAL: For 3M Co. Internal Use Only")—from 3M, Adhesives Coatings and Sealers Division, St. Paul, Minn. 55101; free. The first and better-than-most general background; the second, a clear concise outline of the contents of hundreds of obscure data sheets (but don't buy from them until they get honest enough to supply even approximate price lists).

by Microsculptor

# WIND




CROSS-SECTION OF VENTURI

# WIND ENERGY

HANS MEYER

Wind energy has been used for a long time. The old Dutch type wind mill was pretty crude in its aerodynamics but provided plenty of torque at slow running speeds. Modern windmills run at much higher speeds, are about 80% efficient and have fairly low starting torques.

If the quantity and frequency of wind is good where you live, it is easy to develop a wind powered electrical system to run lights and appliances as well as tools, pumps and other equipment.

Windmills are limited in the amount of energy that they can deliver by the low energy density of the wind and by the inherent limitations of propellors.

The power in the wind can be determined by finding the amount of kinetic energy passing through the area swept by the blade per unit time:

$$\text{energy} = \tfrac{1}{2}\ (\text{mass})\ (\text{velocity})^2$$
$$\text{mass} = (\text{density})\ (\text{volume})$$
$$\text{volume} = (\text{area})\ (\text{velocity})$$
$$\text{power} = \tfrac{1}{2}\ e\ a\ v^3$$

The molecules of air passing through the plane of the propellor have to retain some of their energy so that they can escape. Because of this the most efficient propellors can only extract about 50% of the energy passing through the blade. For sea level air, with the area swept in $ft^2$ and the wind velocity in ft/sec:

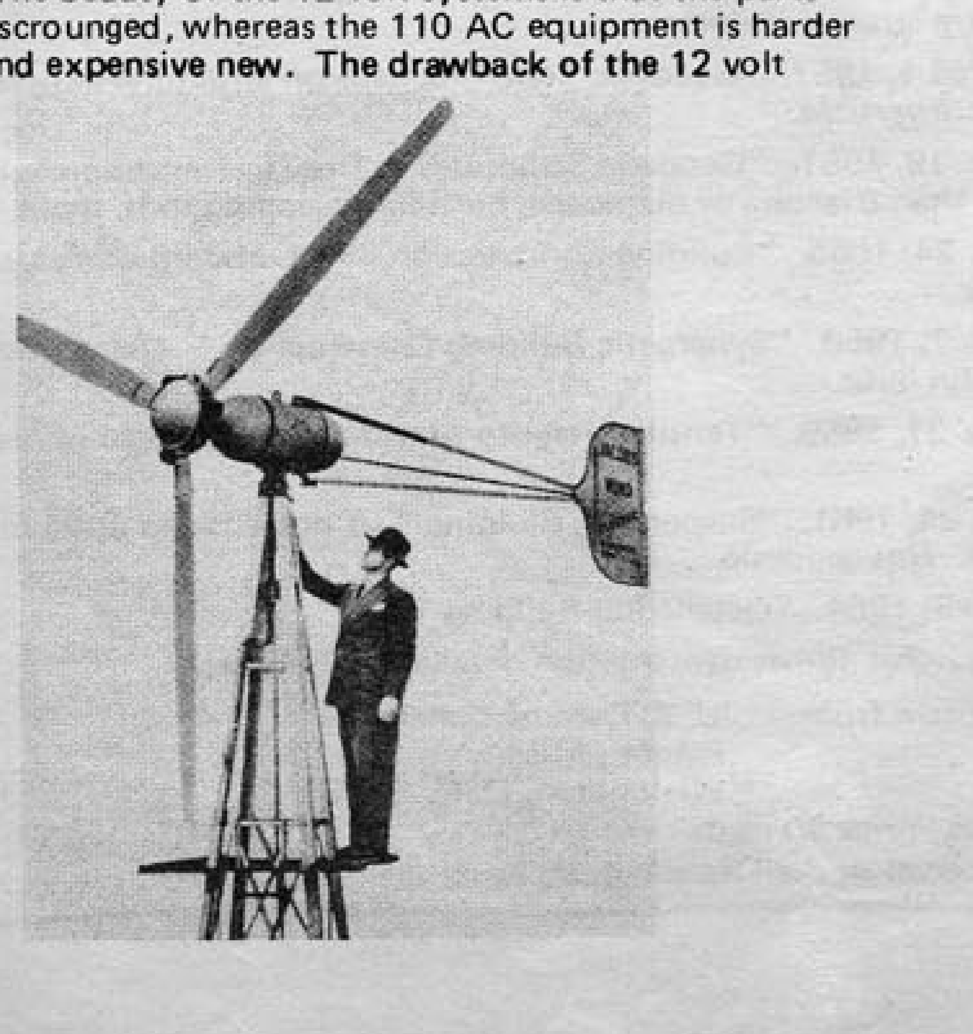
$$\text{usuable power} = 0.102 \times 10^{-5}\ (\text{area})\ (\text{velocity})^3$$

with the power given in horsepower.

With an idea of your power requirements and the usual wind velocity in your area, you can determine the size of blade needed.

## ELECTRICAL SYSTEMS

There are two classes of generators that are readily available: 12 volt DC generators (or alternators) as in cars, and 110 volt AC alternators. The beauty of the 12 volt systems is that the parts can be easily scrounged, whereas the 110 AC equipment is harder to come by and expensive new. The drawback of the 12 volt system is that there is not much you can do with it since most electrical equipment is made to run off standard house current — 110 AC. To gain versatility with the 12 volt system then, it is necessary to change it to 110 AC or DC. Transforming means both more equipment and some loss of energy.



The difficulty in using AC equipment is that you have to run the alternator at constant rpm's to get constant cycles per second. (Household electricity is 60 cycle, 1 phase, 110-120 volt). Since the wind velocity is constantly varying, it is difficult without some control mechanism to run a windmill at constant speed.

All of the above is complicated by the problem of storing energy. DC current can be stored in batteries, but batteries are both limited in capacity and expensive new. And in the end you again have the problem of AC versus DC current.

Other storage systems that are possible are pumping water uphill, storing super-heated steam, or winding up big springs. Either water or steam will require some sort of turbine to convert to electricity.

Again depending on what you want to do with the energy, maybe you can bypass electricity altogether and use the mechanical energy of the blade directly. We are working on a new air system for both storage and direct power.

Here are four fairly simple electrical systems that we have been thinking about that can be wind-powered. Each one has different advantages and disadvantages, and each can do things the other may not.

## 12 VOLT DC SYSTEMS

12 volt systems are the least expensive and easiest to set up, and can provide energy for lights and water and other simple 12 volt equipment. Use the generator (or alternator and rectifier) and the regulator out of an old car. Tail lights are the same as the tensor lights. Most water pumps on cruising sailboats are 12 volt and can be gotten through marine dealers.

With a 12 volt system the equipment runs off the battery. The windmill powers the generator to recharge the batteries. A single battery will hold enough charge for a day or two depending on how much you use it, and will recharge in less than an hour in a moderate wind.

## 120 VOLT DC SYSTEMS

There is a lot more that you can do by jumping the voltage up to 120 but still using DC current. Any series wound, brush-type electric motor that is made to run on 120 AC will run just as well on DC. It is not that important to exactly regulate the voltage using DC. Motors can be run at higher or lower voltage (hence rpm's) without burning them out. With AC you can't vary the voltage more than 5 to 10% without damaging the motor.

To get a 120 volt system you can again use car parts in several different ways. With a transformer, the energy from the generator can be used directly. As the wind varies the amperage will vary, hence the total power will vary.

If you are good at finding old batteries, 12 batteries can be wired in series to give 120 volts. The generator is wired in to recharge the batteries.

The amount of sophistication needed to get either the 12 or 120 volt systems to work is practically nil. The crudest of windmills will be able to recharge the batteries.

## 12 VOLT-110 AC SYSTEMS

To power induction motors, refrigerators, bench saws, drill presses or your color TV, you need to generate 110 AC. If the amount of power that you need is not too great, then you can still use a 12 volt setup and a convertor or invertor. Sears distributes a 450 watt solid state invertor for $120 that goes from 12 volt DC to 110 AC. 450 watts is enough to power most ¼" drills, four and a half 100 watt lightbulbs, etc.

The invertor runs off a 12 volt battery with the windmill hooked up to recharge the battery. There must be some larger invertors on the market, but I haven't had time to track them down yet.

## 110 AC SYSTEMS

By using some means of regulating the speed of the alternator it is possible to generate 120 AC directly. To get constant rpm's you can regulate the airflow, the propellor, or the power transmitted to the generator. Slip clutches have been developed to limit the power transmitted. Coning devices and variable pitch propellors limit the amount of energy extracted from the airstream passing through the plane of the propellor.

Turning on your windmill is not without problems. First there is the erratic nature of the wind, and then there are the difficulties of energy conversion. In the end it all comes down to the same thing of turning on or plugging in.

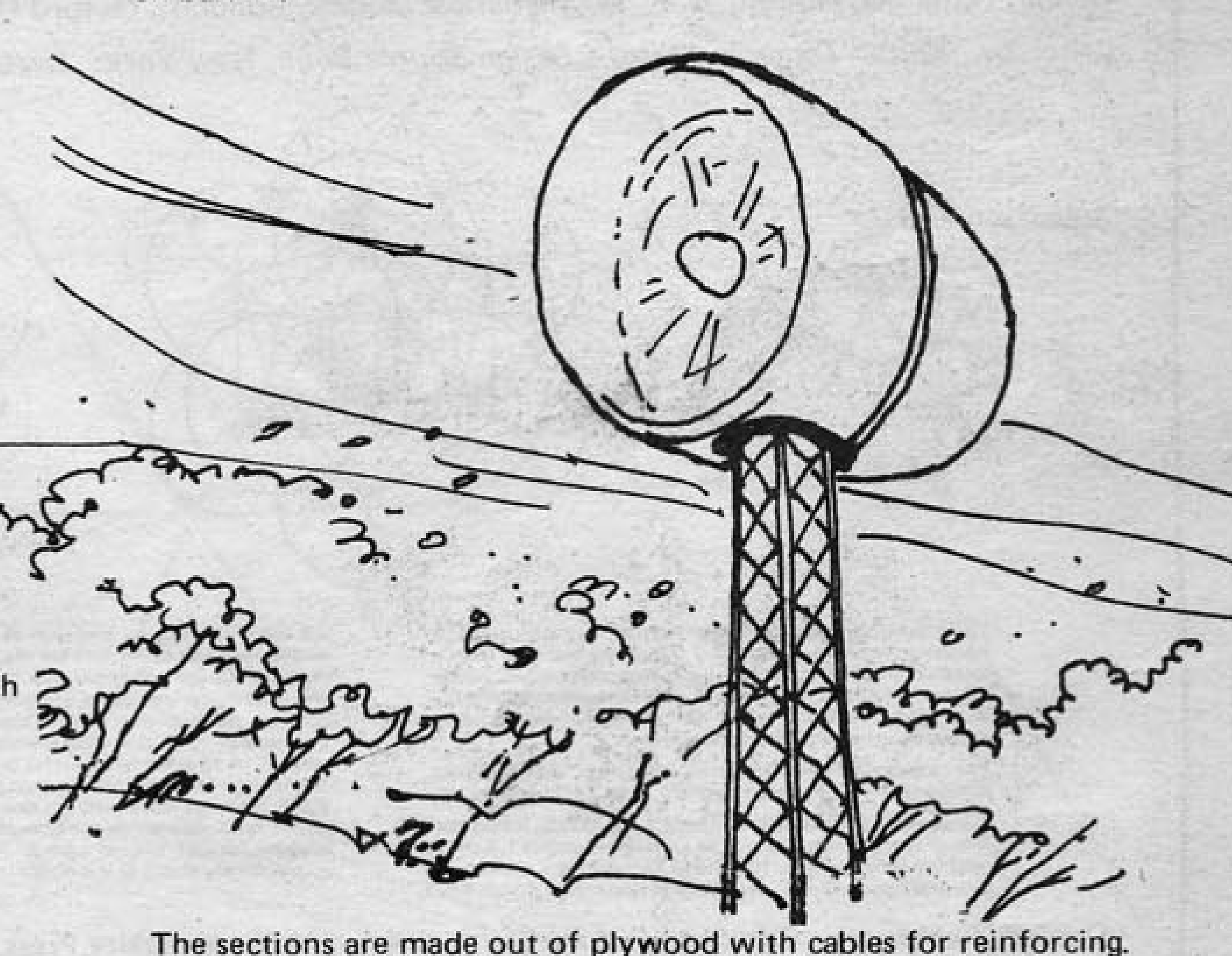
## VENTURI WIND GENERATOR

We have just about finished building a ducted windmill. The shroud around the blade lets us limit the airflow through the blade, which should allow us to run at constant rpms. The idea behind the shroud is that by shaping the inside surface like a venturi tube, the velocity of the airstream can be increased up to 100%. Since the power in the wind is proportional to the cube of the velocity, doubling the velocity gives eight times the power. Then, besides allowing for control, the shroud reduces the blade losses in the same way that a wind's efficiency is increased by attaching an endplate.

By using vanes in the diffuser section of the shroud we should be able to regulate the flow to get constant rpms within some margin or error. Then, whenever the wind speed is above some minimum, the generator can be engaged, with the vanes working to prevent the flow from exceeding the designed speed.

The shroud will look a lot like a jet engine pod from the outside. The inside surface will form a venturi tube with the propellor mounted at the narrowest section. The shape is generated by rotating the airfoil section about an axis in line with the axle of the propellor.

The shell is in four sections for portability. The mating surfaces have lugs for alignment — two sets of internal cables hold the sections together. The sections are like staves and the cables like the bands on barrels.



The sections are made out of plywood with cables for reinforcing. Battens are laid across the plywood bulkheads with muslin stretched over them to get the surface. The muslin is 3 oz material used for floor bags and is smooth and stretchy. On top of the muslin we put a layer of 2 oz fiberglass for strength.

An aluminum channel platform fits into the bottom section. The platform bolts to the hub that is part of the tower. The hub allows the shroud to rotate with changes in wind direction.

The propellor hub is supported by three struts: one vertical and one running to each side of the platform. The propellor rides on the axle of a Harley Motorcycle — the struts clamp onto the hub that the wheel would normally ride on. The other end of the axle carries the sprocket and chain. The generator is mounted inside the shroud bolted to the platform.

The propellor has a ¾" seamless steel pipe for a shaft. The propellor section (NACA 4418) was cut out of unexpanded paper hexcel with a hole drilled in it for the shaft. The honeycomb was expanded onto the shaft, rotated to assume the proper angle of attack and cemented into place. The surface was then fiberglassed.

Srping-loaded vanes are mounted at the exit. When the wind exceeds some predetermined value, they will begin to close down and limit the amount of flow.

## WINDMILL DESIGN

Free-standing windmills with 12 volt systems can be built by anyone. The only critical parts are the design of the blade and the hub that it rides on.

The design of the blade can be gotten from Hutter's article in volume 7 of the UN Conference on New Sources of Energy. He has reduced the problem of optimum blade design to several sets of curves that can be overlapped to find the best operating conditions.

Car hubs with a little extra welding can be made into good hubs for the propellor. Or the whole back end of a car can be used, stood on end. The rpms of the blade can be held more nearly constant in different winds by using different gears.

People who are working with wind energy, or other types of non-polluting energy, ought to write. If you are building a windmill and need help, I'll do what I can. In the next year or so, I want to get a number of the different types of windmills that I am working on built and tested. Than at the end of that time, if there is enough information along with what others send in, we can try to publish something for others to work from.

Write in care of Pacific Domes.

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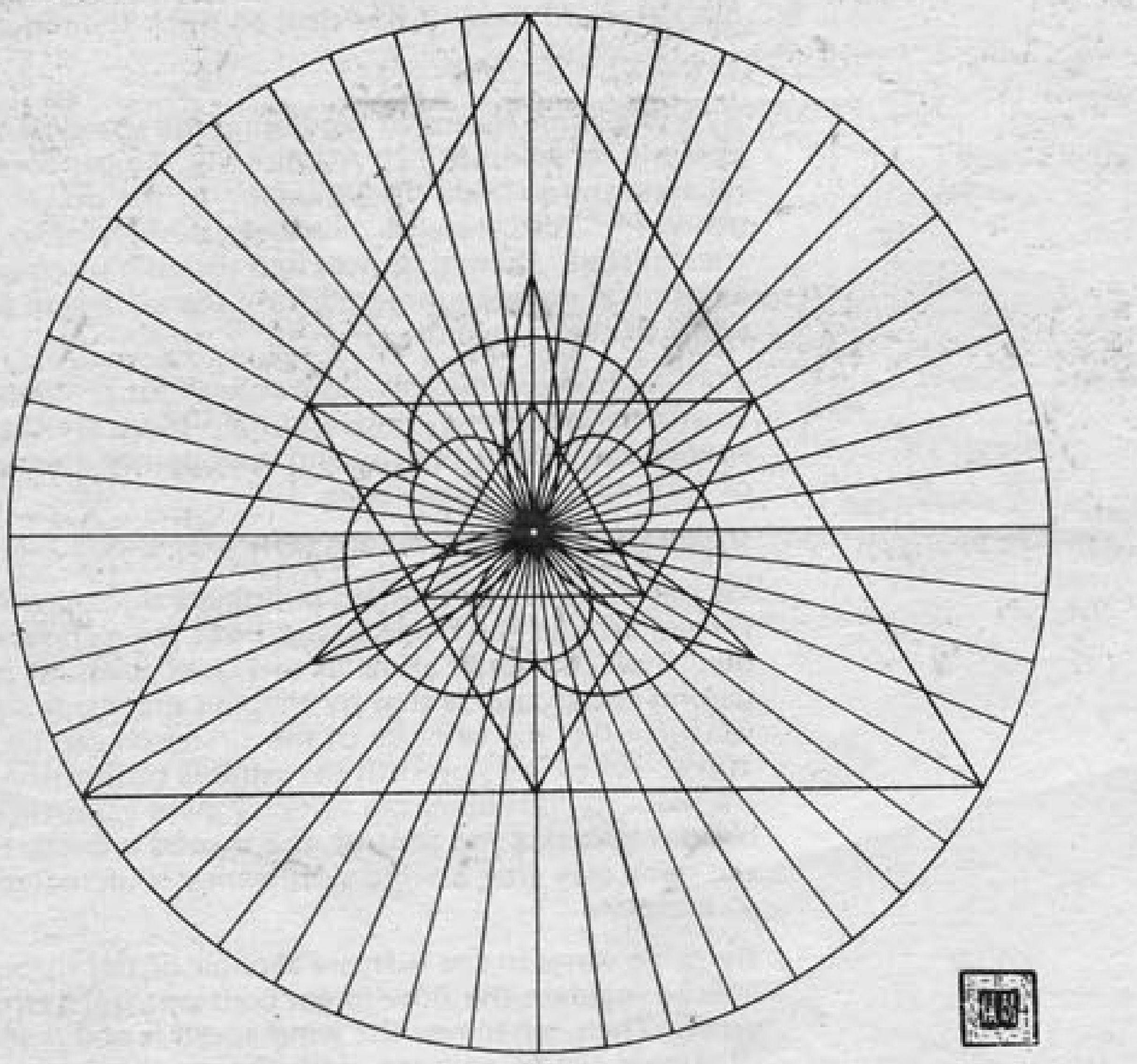

*From Patterns in Space*

Conchoidal Transformation of Triangles. When all points in sides of the three triangles move in at the same rate on their lines through center, they will form the floral pattern when midpoints of outer sides meet at the center.


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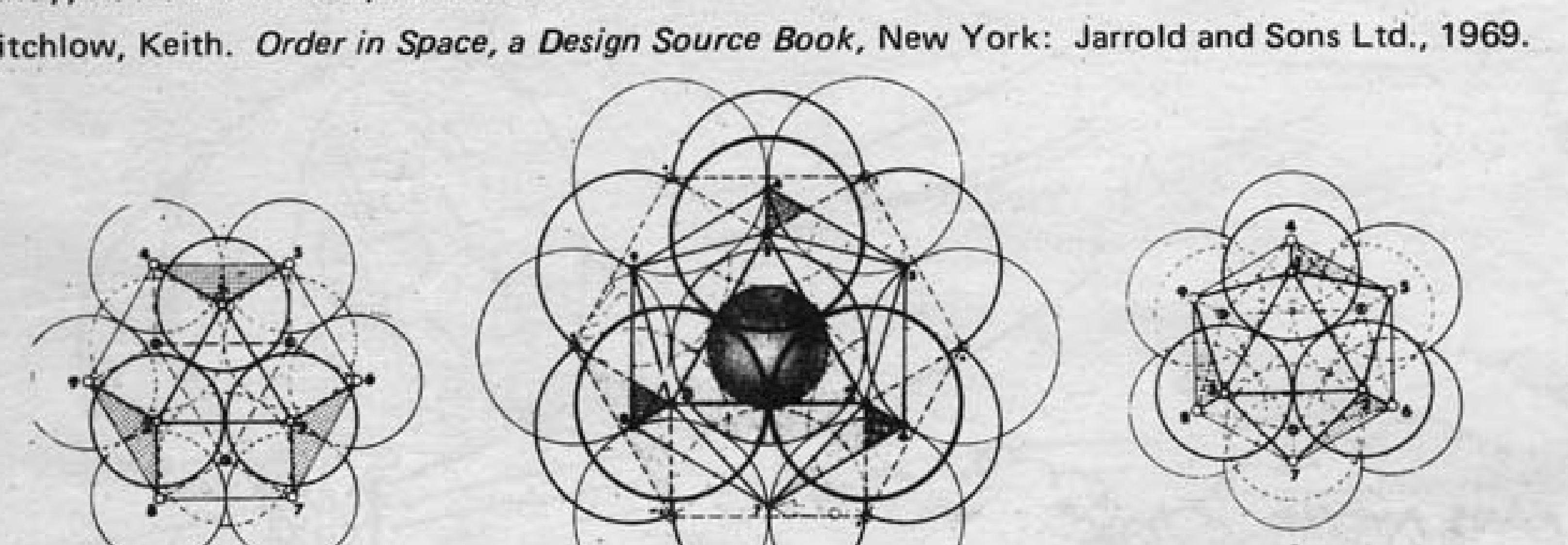

A B C

These drawings show the change from a cuboctahedral pattern (twelve spheres around an equal and similar nucleus) to an icosahedral pattern (twelve spheres without an equal nuclear sphere). The variation in size of possible nuclear spheres is shown in the middle drawing, with the maximum size lightly shaded and the minimum darkly shaded.

The *cuboctahedron* or *dymaxion* in figure A, with its points numbered 1—12, is viewed centrally in its 3-fold axis.

The central figure, B, still viewed in a 3-fold axis, shows the change to the *icosahedron.* The position of points 1,2 and 3 (and the corresponding 10, 11 and 12, which are not shown) does not change in this view; but the position of points 4,5,6, 7,8 and 9 does change, and each of these is shown in two positions, smaller numbers being used for the first, larger ones for the final position. Of the eight triangular faces of the initial figure, the two directly central, above and below, remain in the same rotational position, although they close in towards each other; the remaining six triangles, three above the meridian and three below, rotate to close in. A tone has been put on the three upper triangles to show the nature of this rotation, in both positions, with arrows following the direction of movement. In this way it is possible to see how the square faces close across their diagonals to create two equilateral triangles for each original square. The final icosahedral position, C, is structurally stable as it is a totally triangulated configuration.


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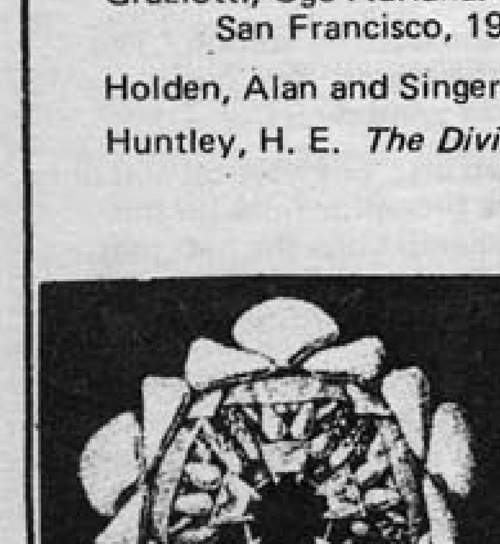

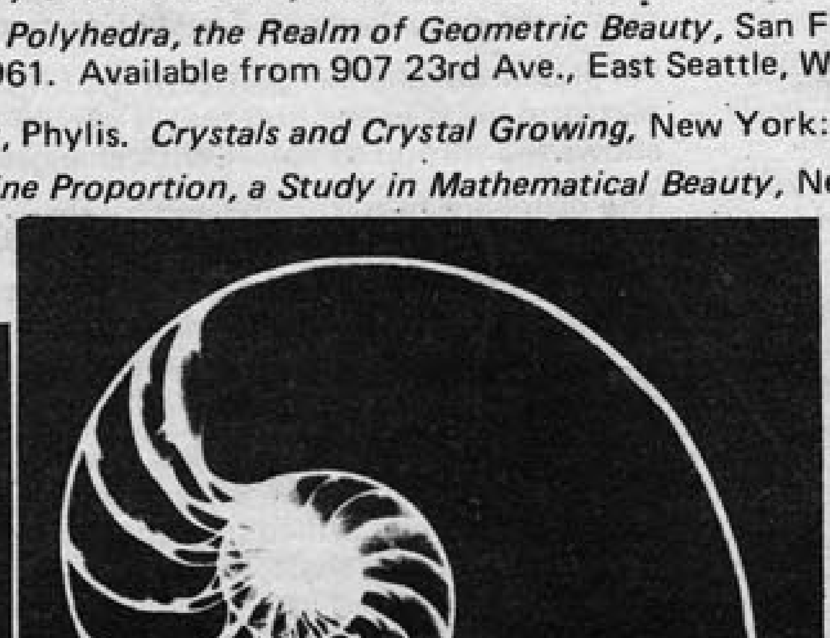

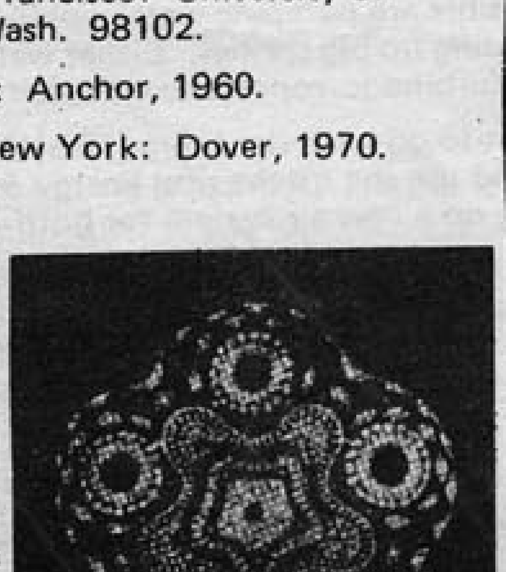


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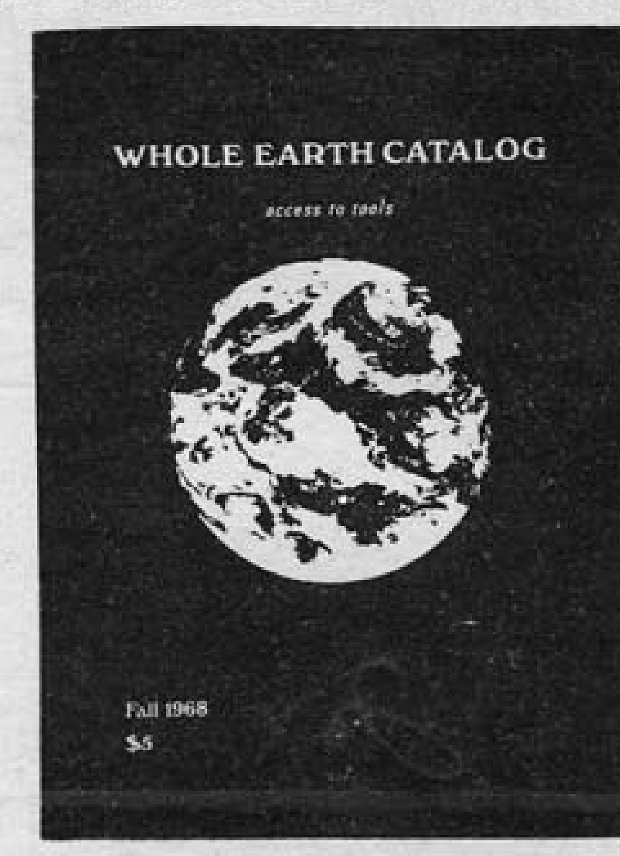


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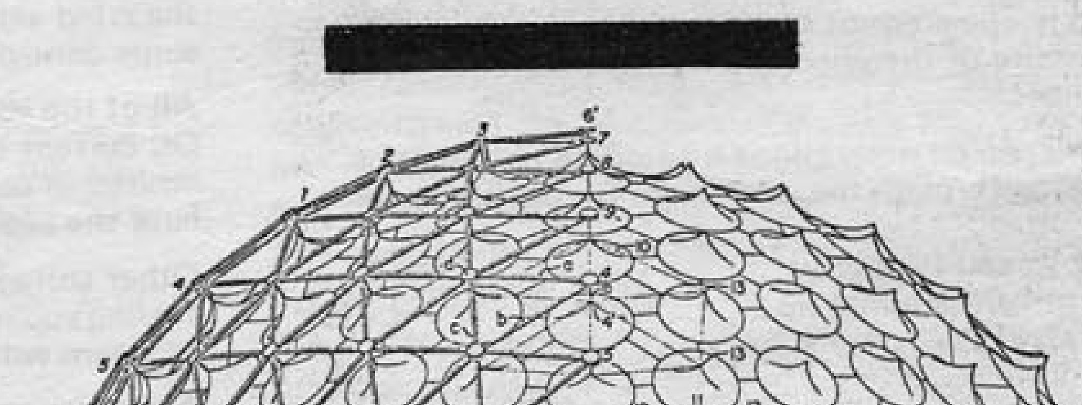

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Obtain from: U. S. Dept of Commerce<br>Patent Office<br>Washington, D. C. 20231

Base price 50 cents<br>Special air mail handling, 50 cents each patent.

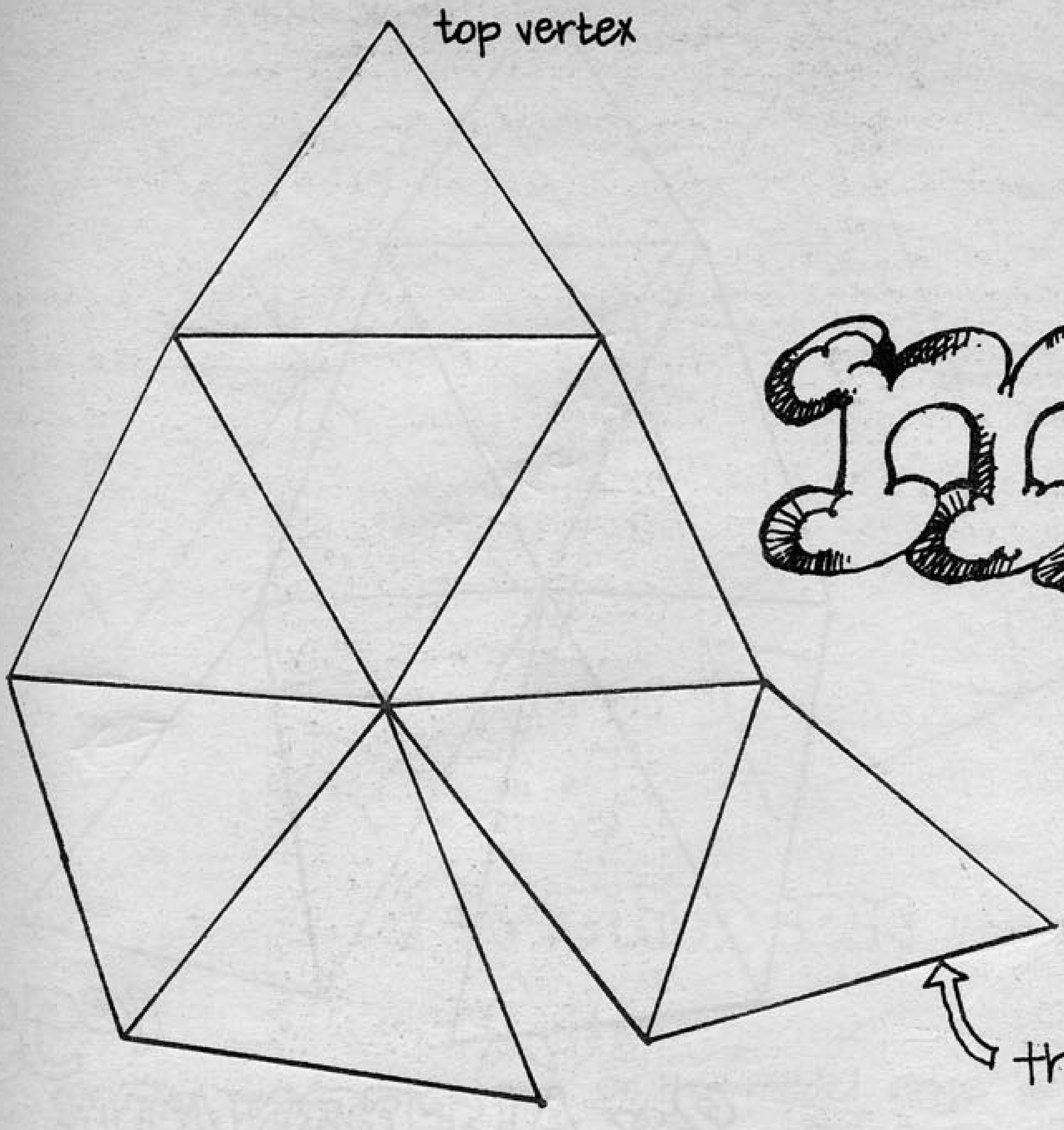


X

# paper models

By tracing these peels you can make the models pictured. Trace the peel five times for the icosahedron based domes, four times for the octahedron based domes. Cut out, including the gathering angles, then tape the gathering angles together to form curved sections. Then tape all the sections together to make the model.

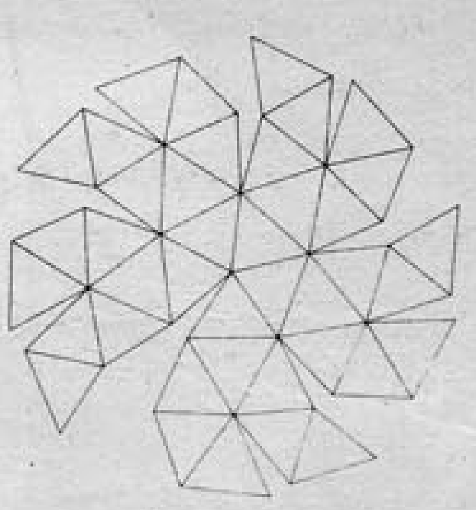
To draw a template of your own, figure the lengths from chord factors, then draw the various lengths with a compass, leaving one gathering angle around each vertex.



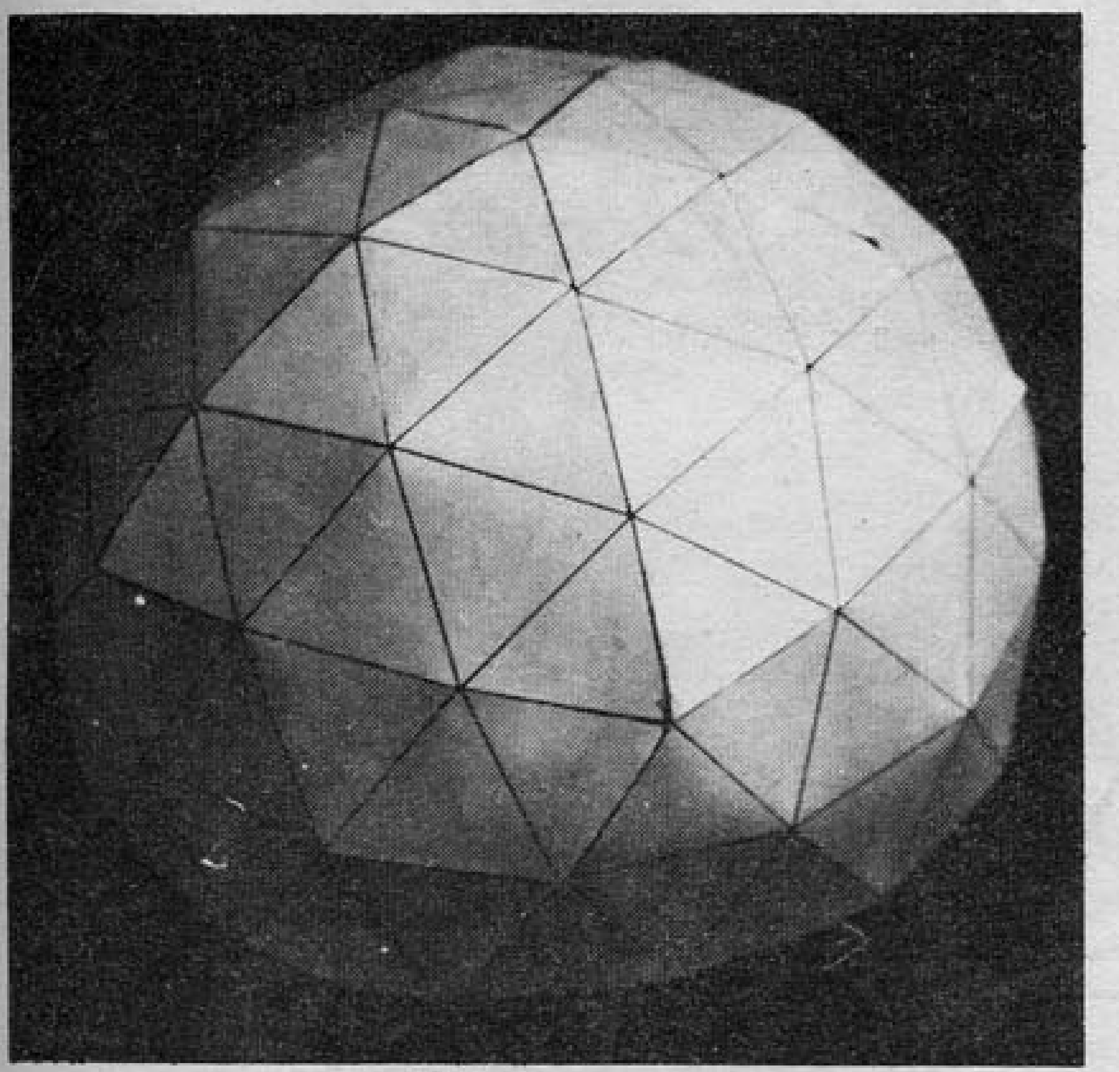

the peel

**2v ALTERNATE** ½ sphere

this is from an icosa, make 5

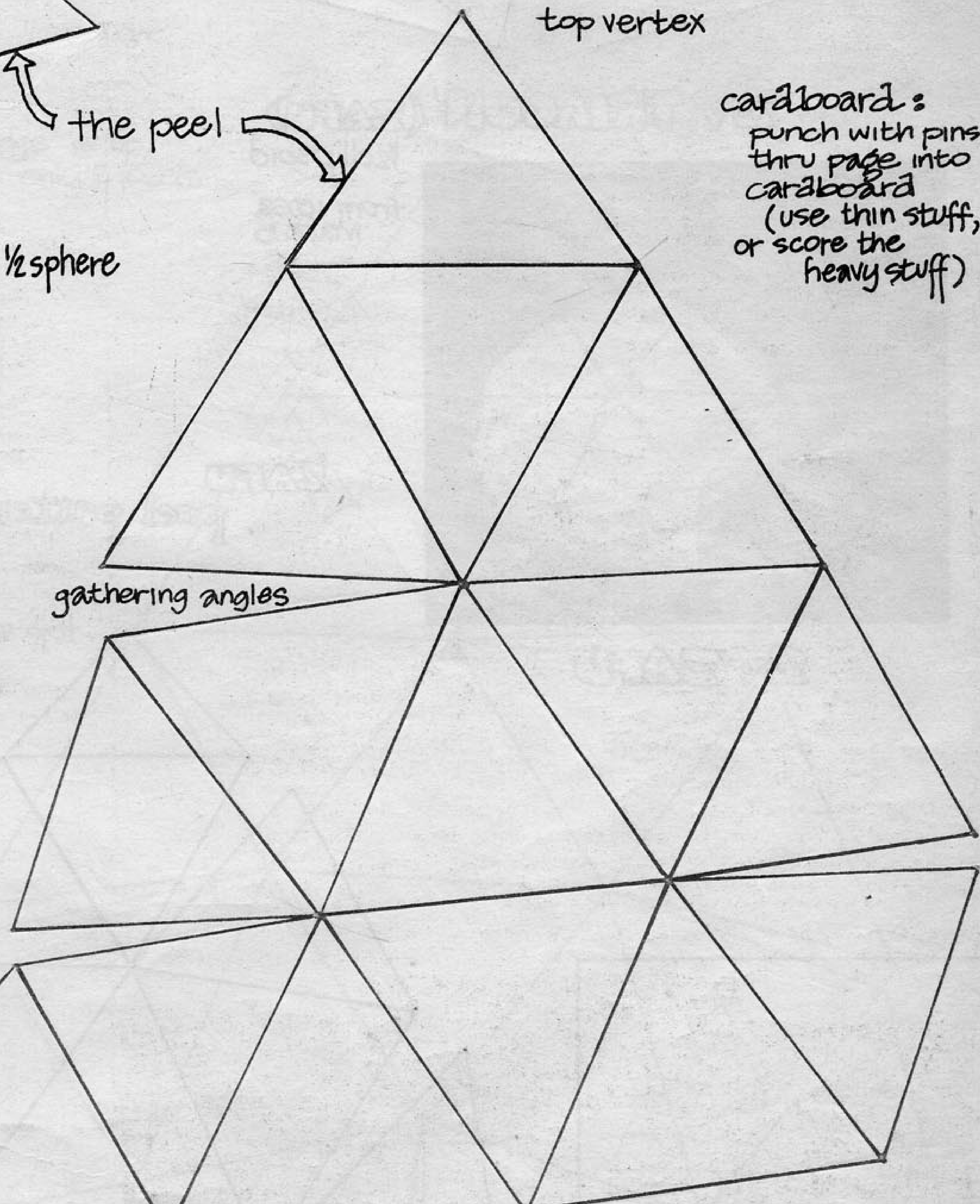


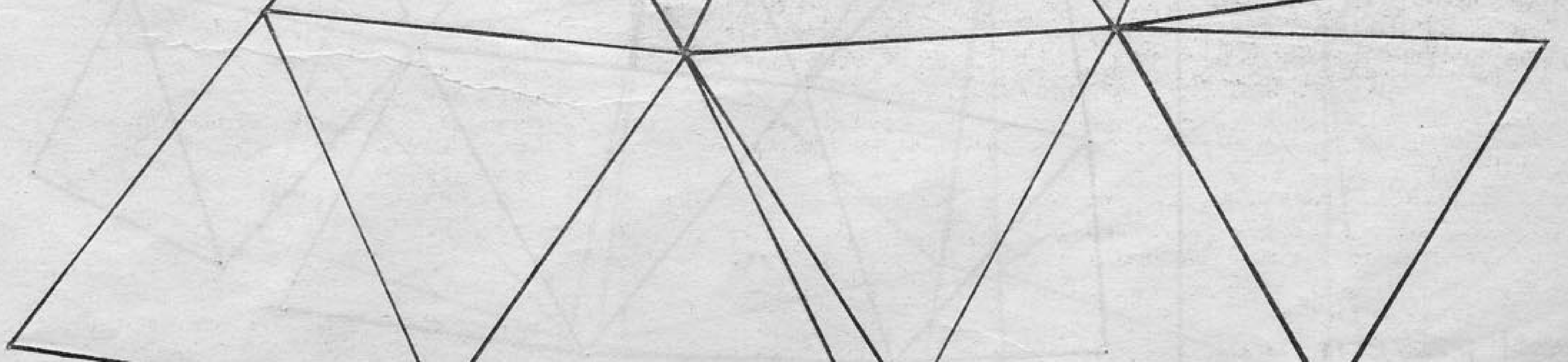
peel pattern 2v



3v

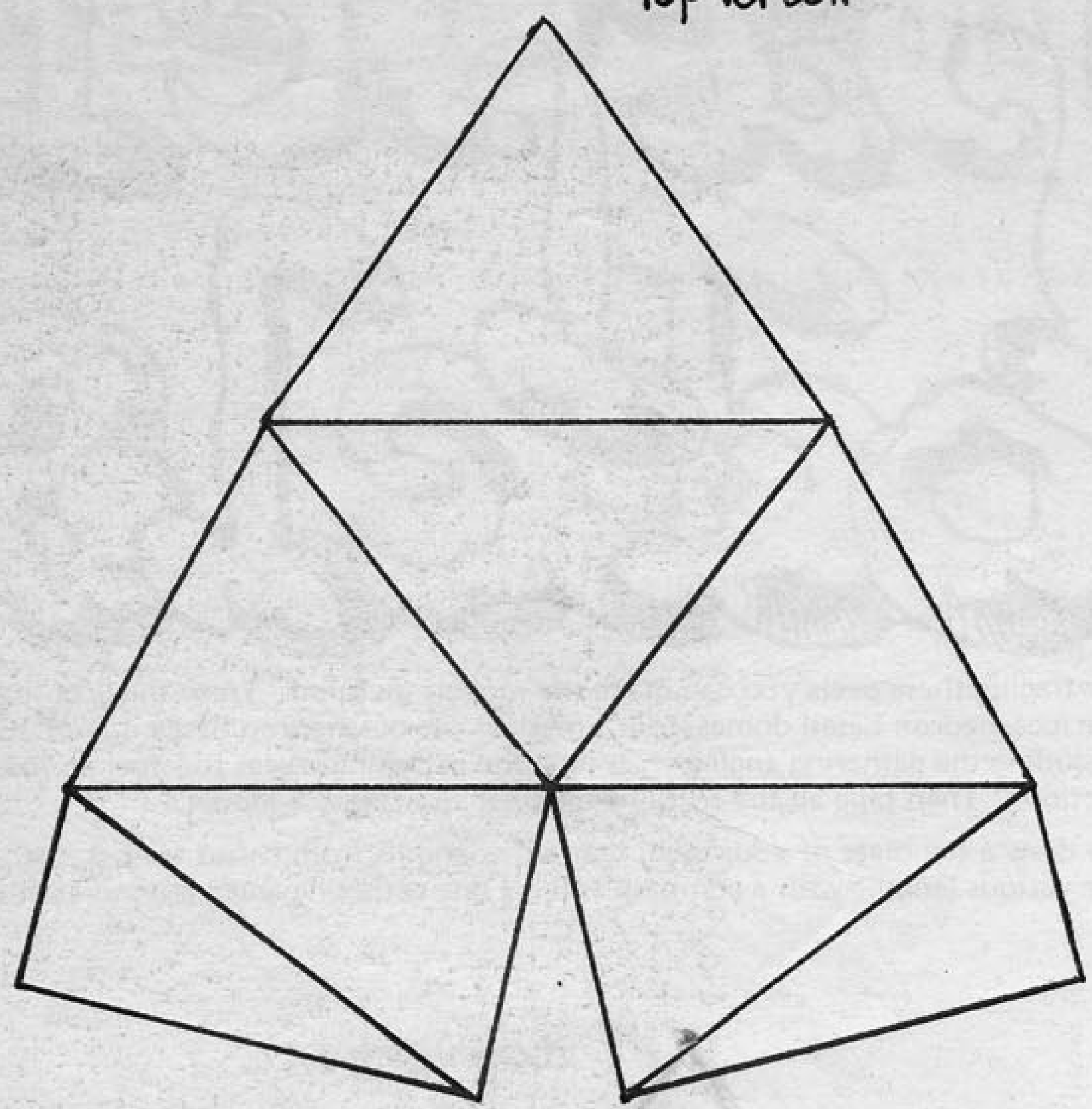
cardboard: punch with pins thru page into cardboard (use thin stuff, or score the heavy stuff)



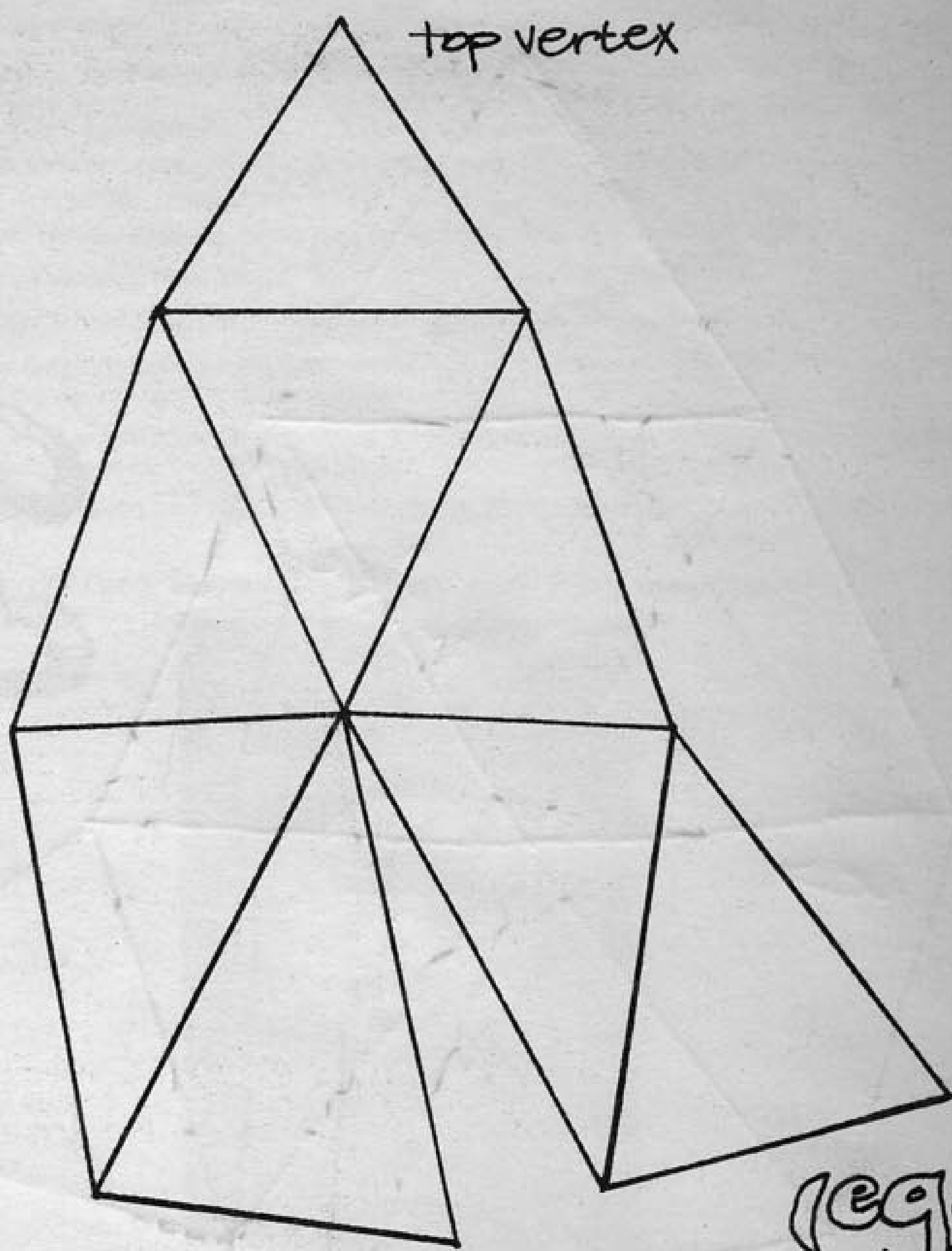



from icosa make 5

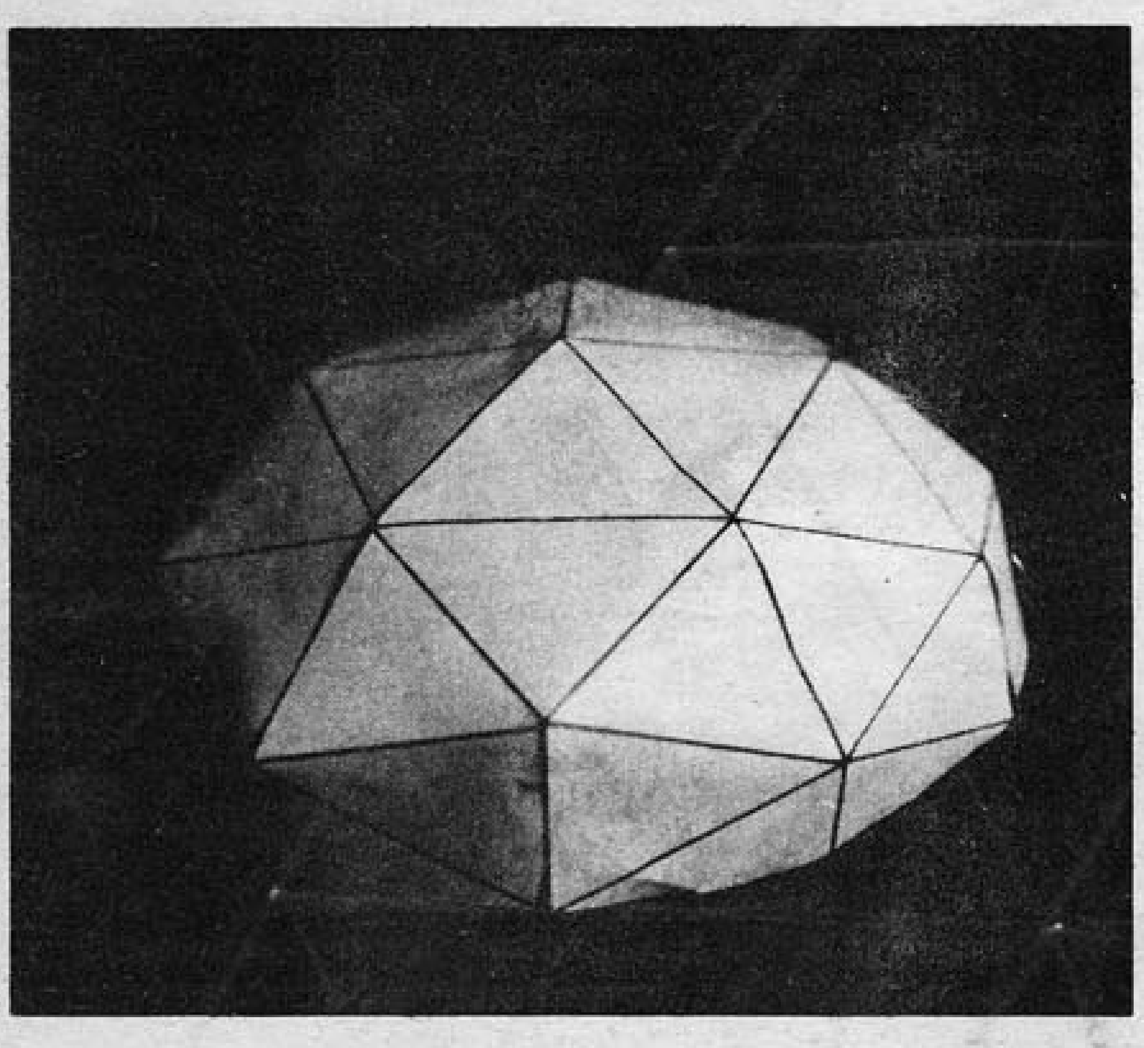
**3v ALTERNATE** 5/8 sphere
the Pacific Dome




**2v TRIACON (ZAFU)**
1/2 ellipsoid

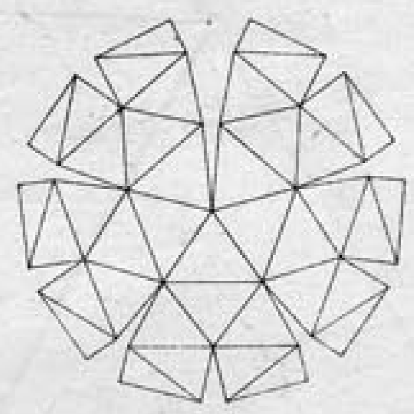



(egg)
**2v ALTERNATE**
1/2 ellipsoid



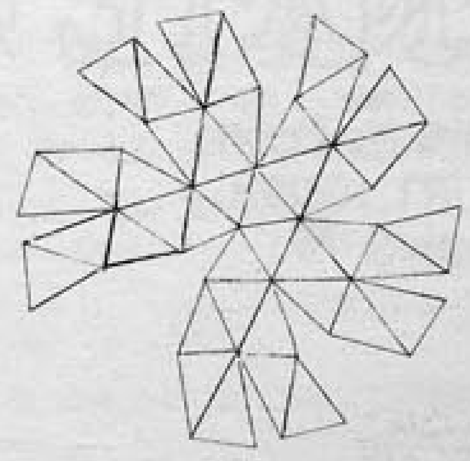
**2v ZAFU**

from icosa
make 5

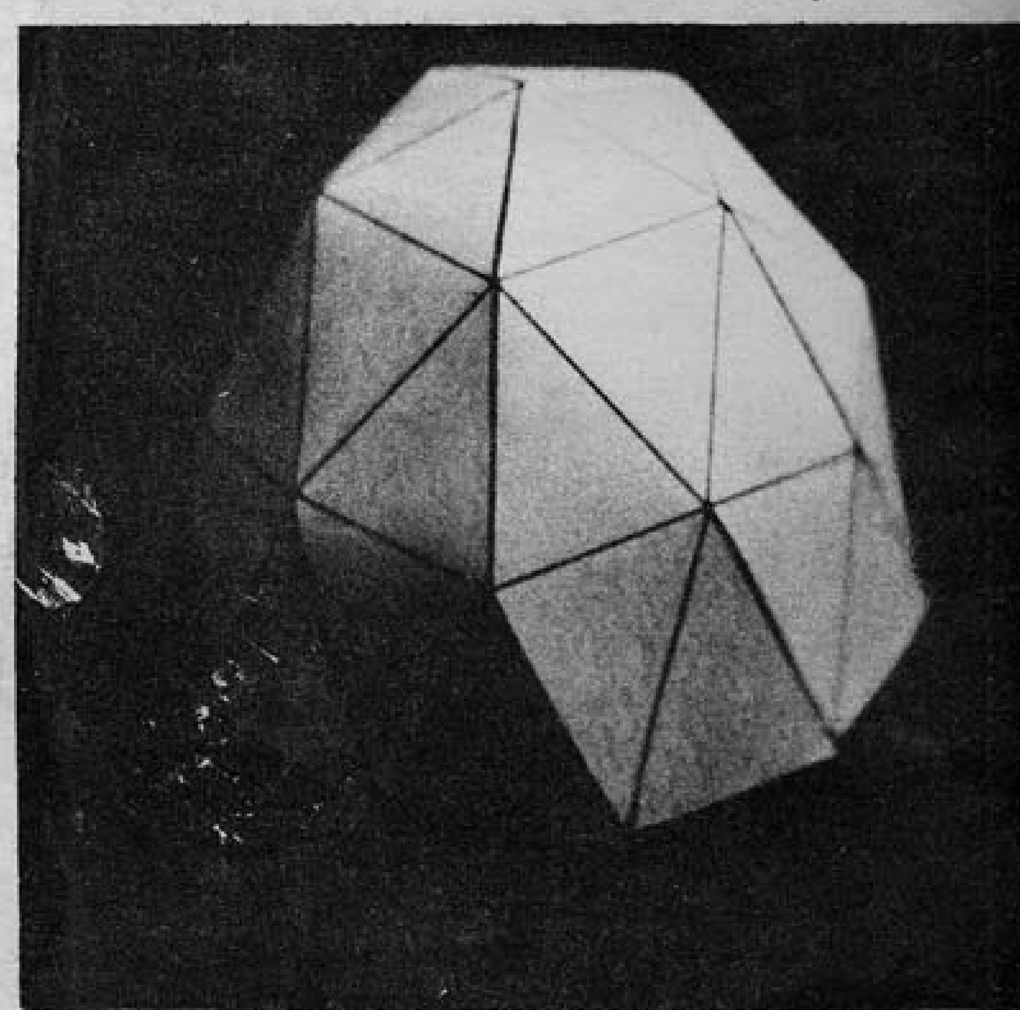


ZAFU

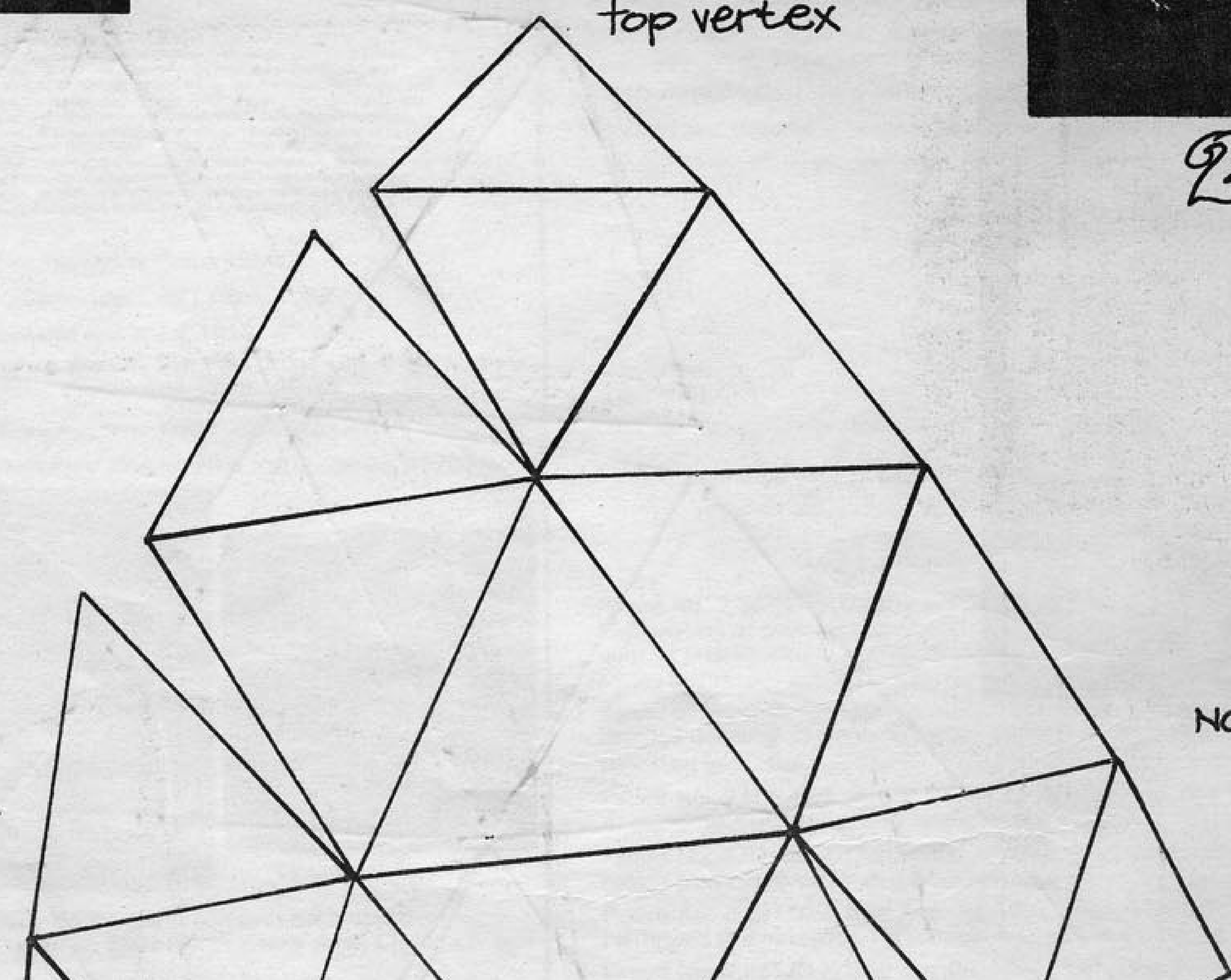
make 5



egg
peel patterns

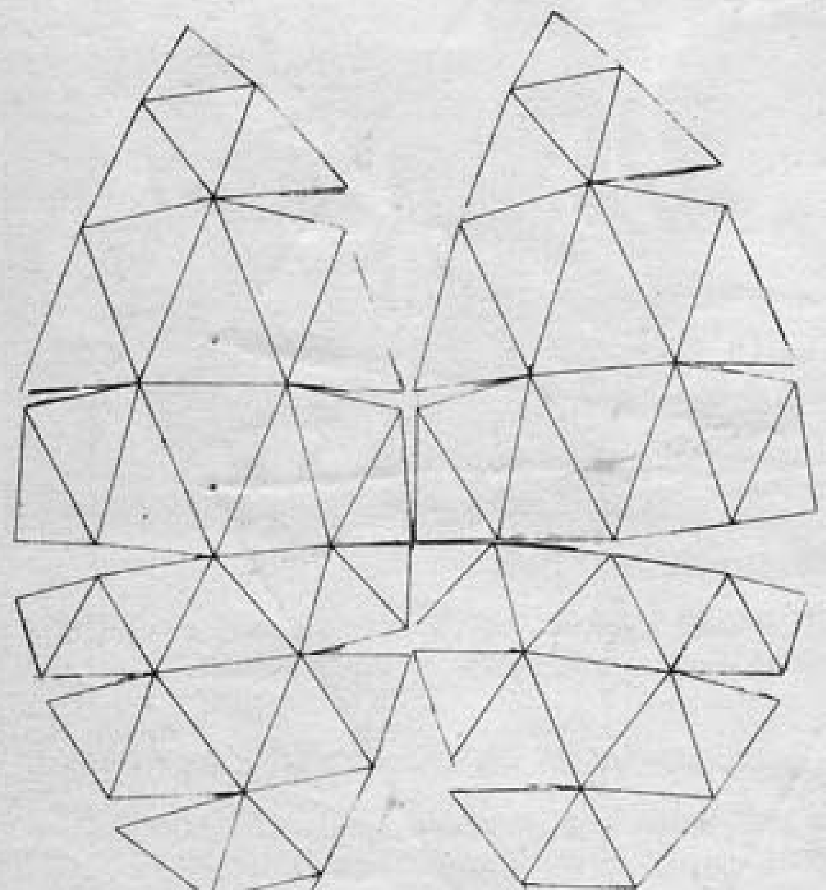


**2v egg**

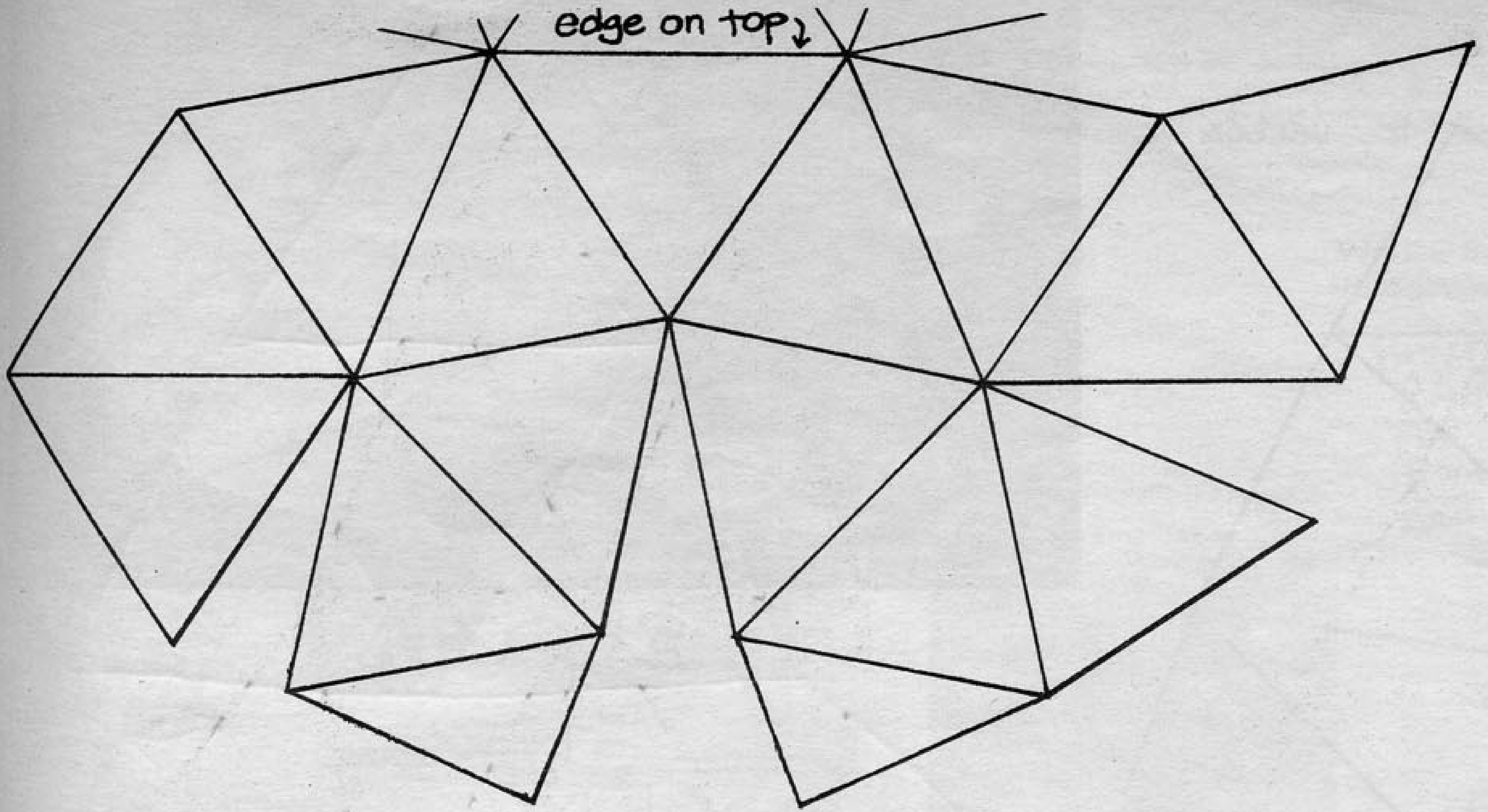



NO peel pattern available, from octahedron, make 4

**4v OCTAHEDRON** 1/2 sphere

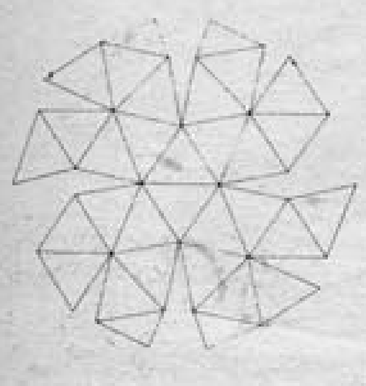


peel pattern
1/4 sphere and 1/4 ellipsoid octahedron can be combined

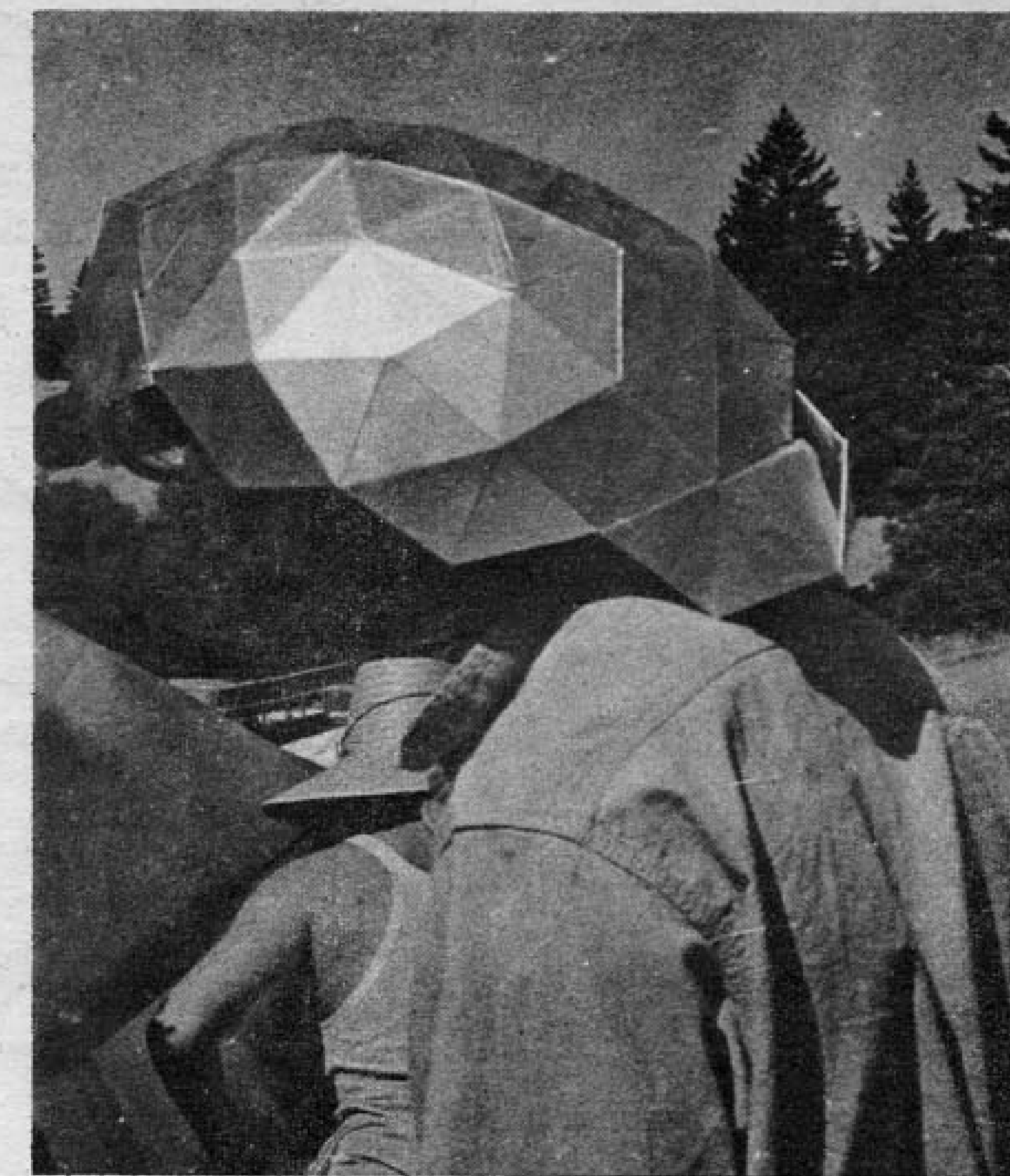



**2v TRIACON** 1/2 sphere

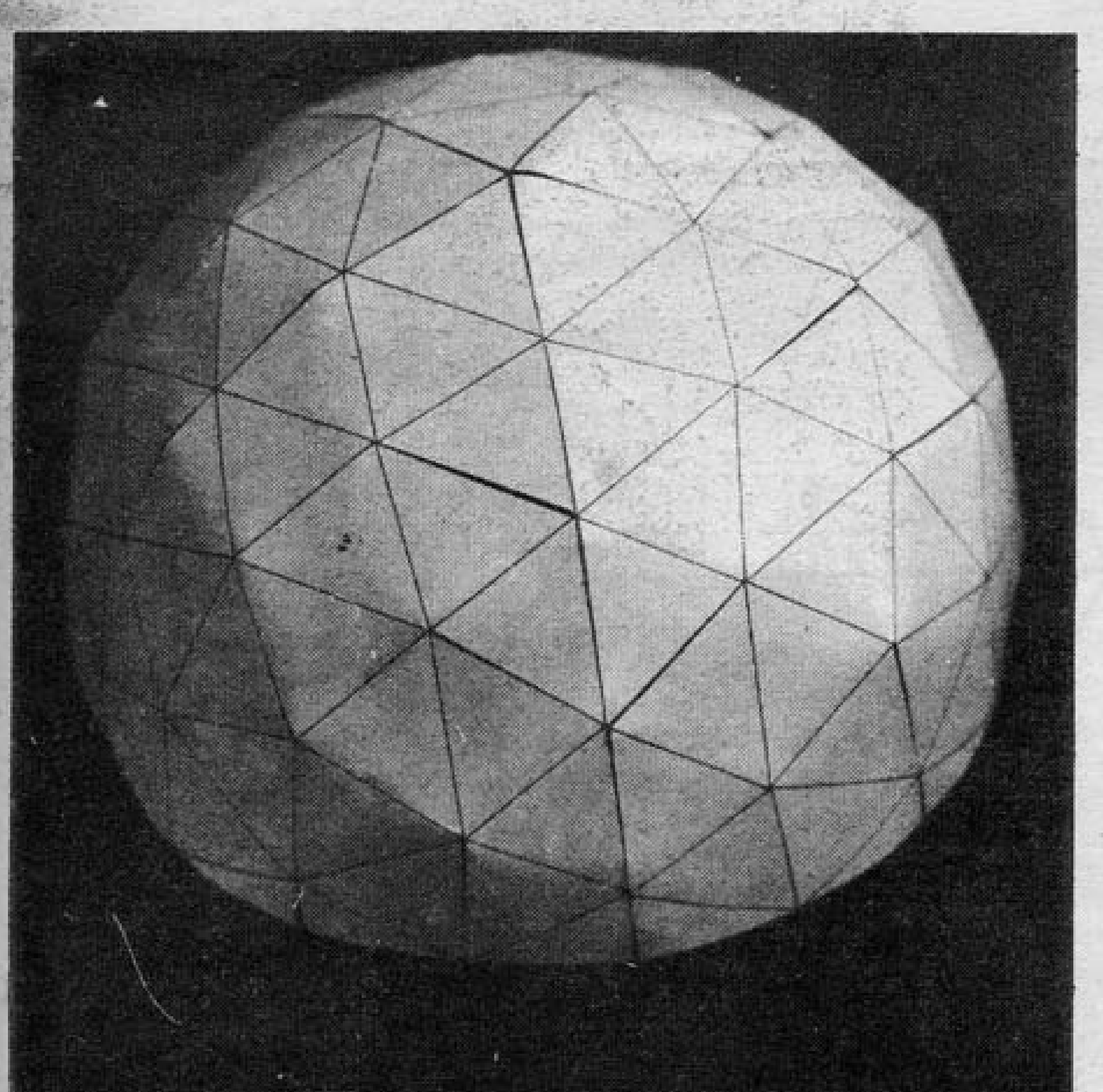
★ **NOTE:** on this model, edge is up, make only 2 peels



**2v TRIACON** peel pattern

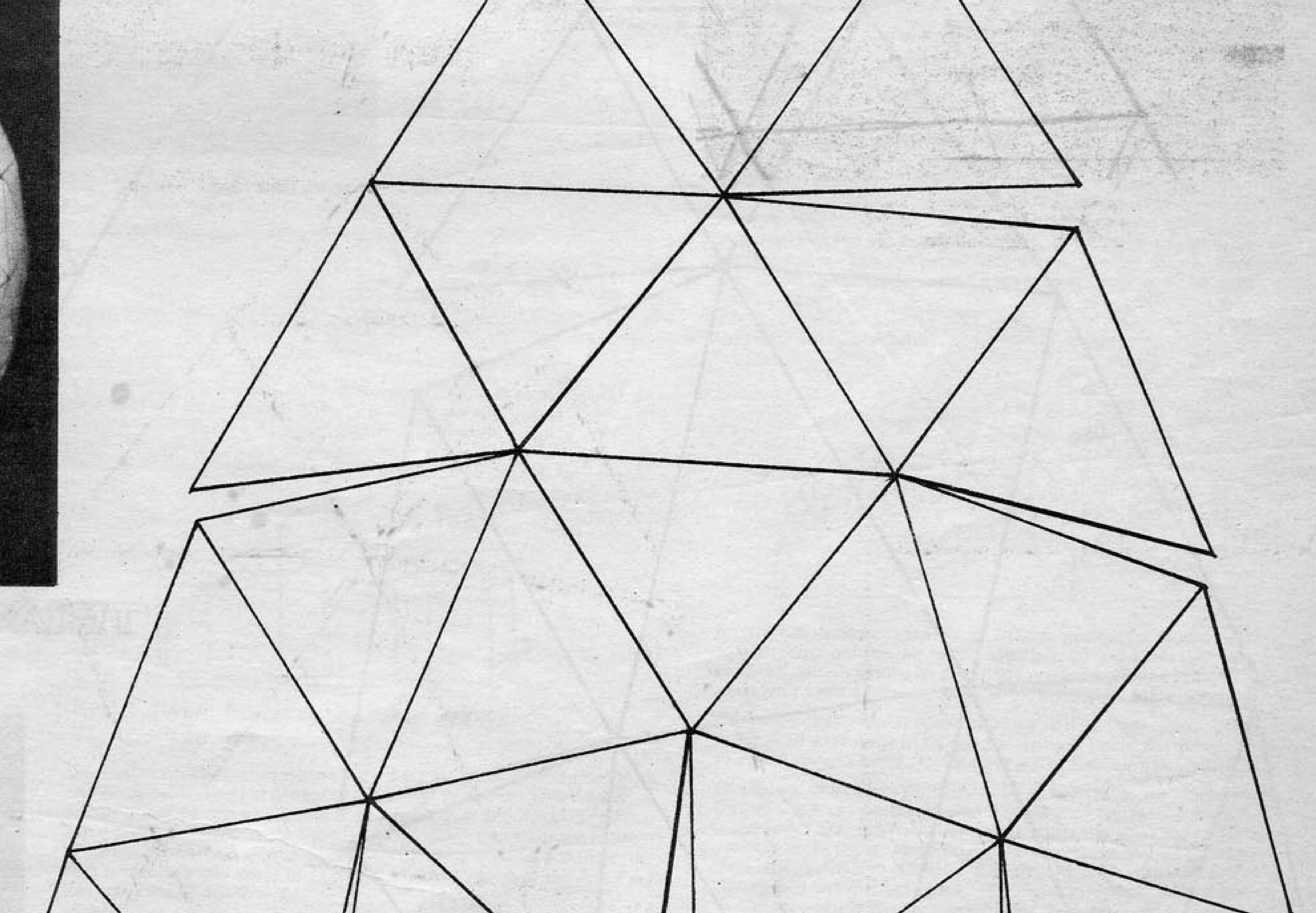


**4v TRIACON**

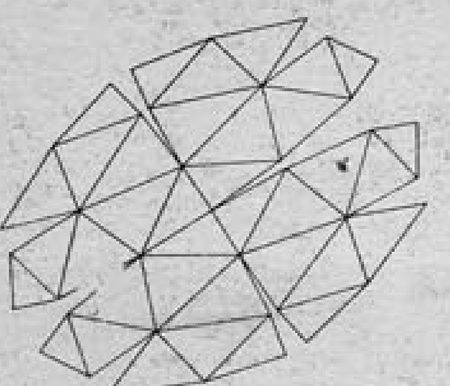


**4v TRIACON**

no peel pattern
make 5

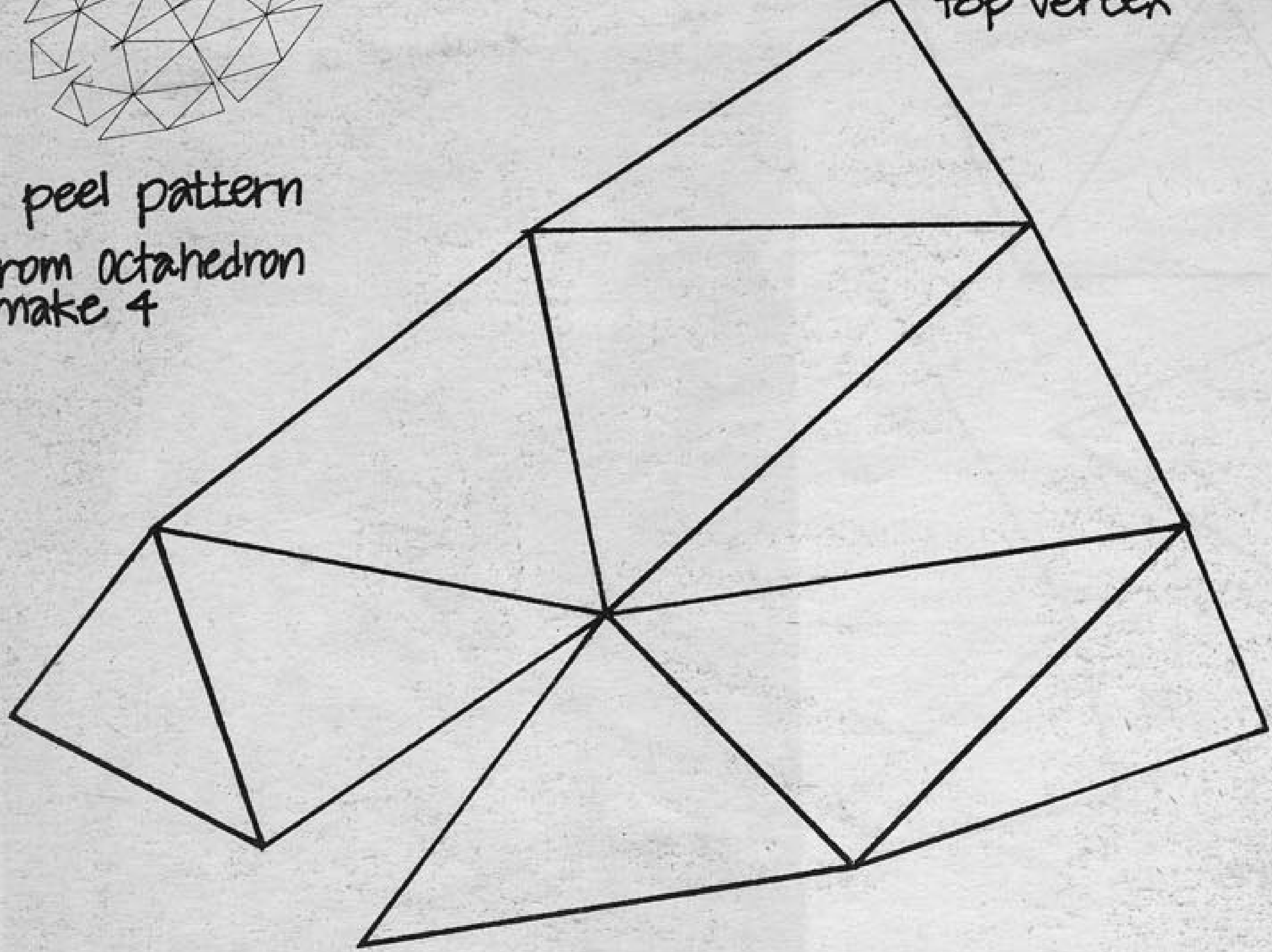



**4v TRIACON** 1/2 sphere
the Aluminum Triacon Dome



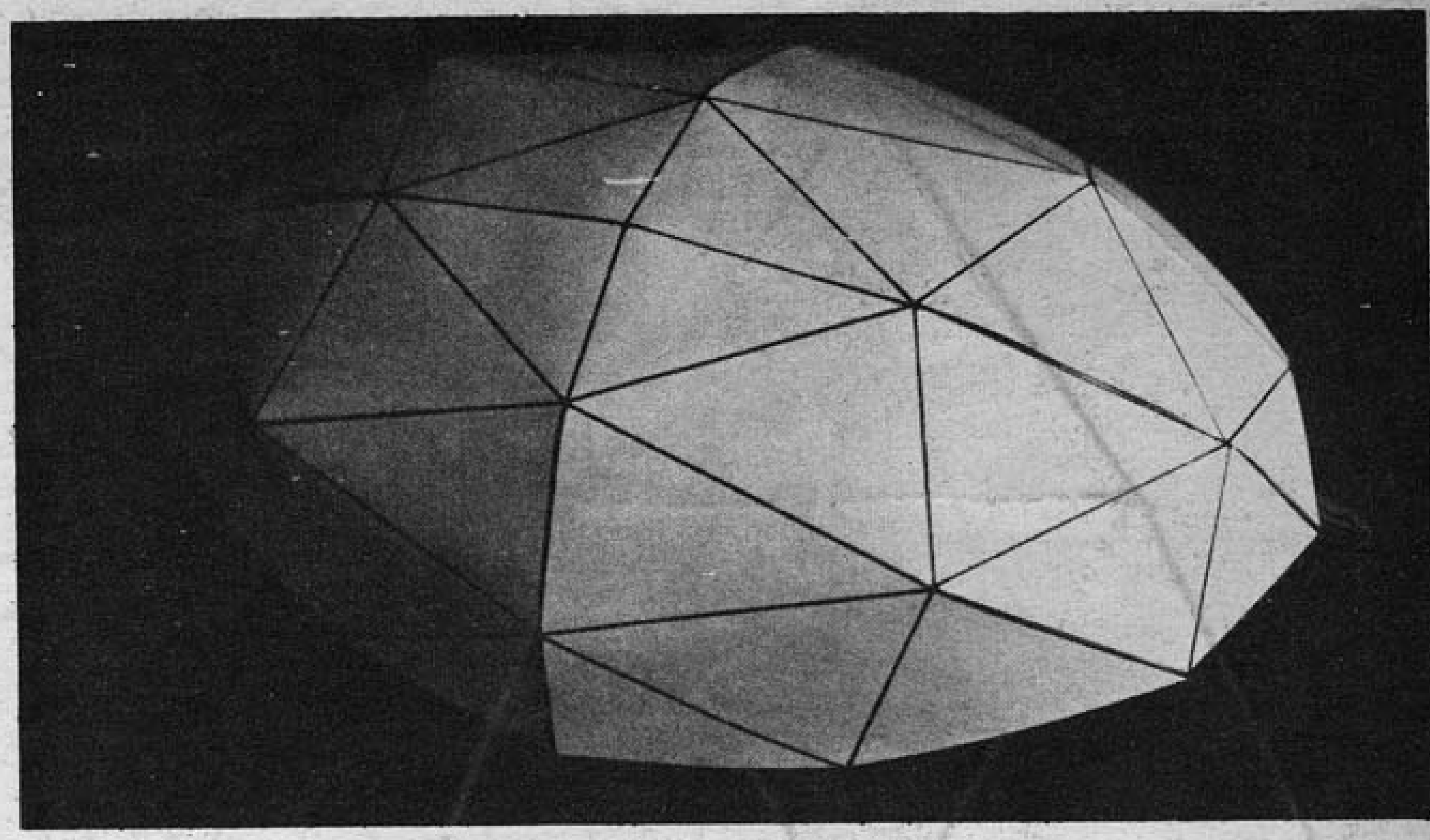
peel pattern
from octahedron
make 4

top vertex



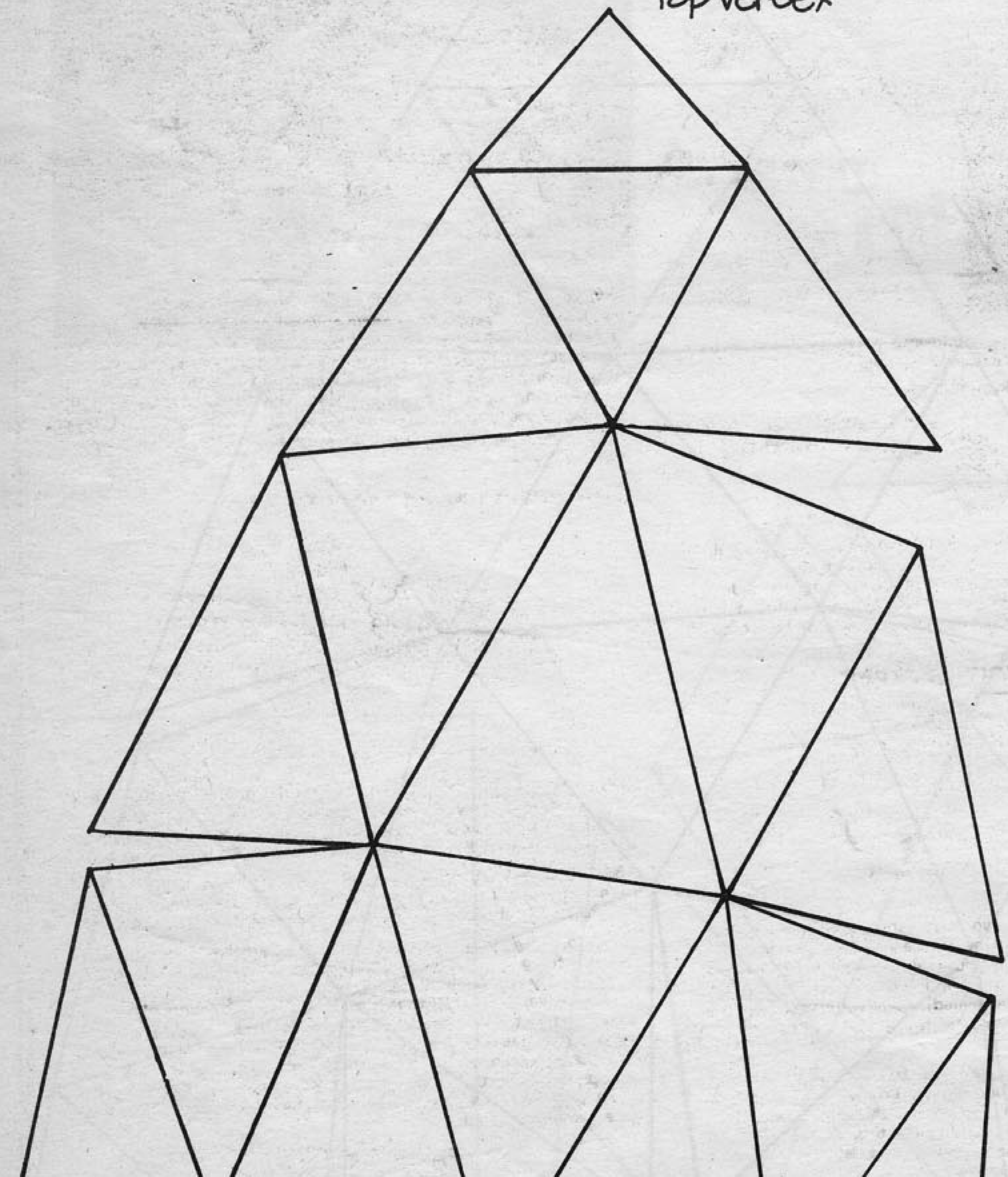
# 3v OCTAHEDRON

Double Expanded
(stretched and squashed)
1/2 ellipsoid



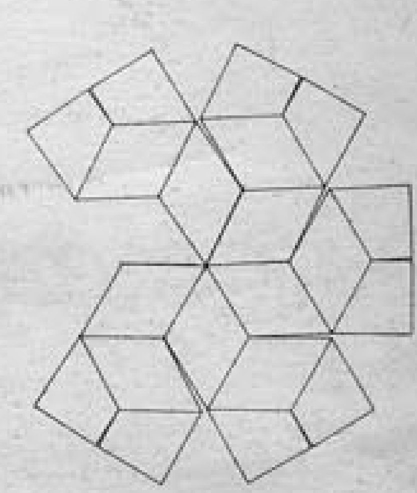
# 3v OCTA

top vertex



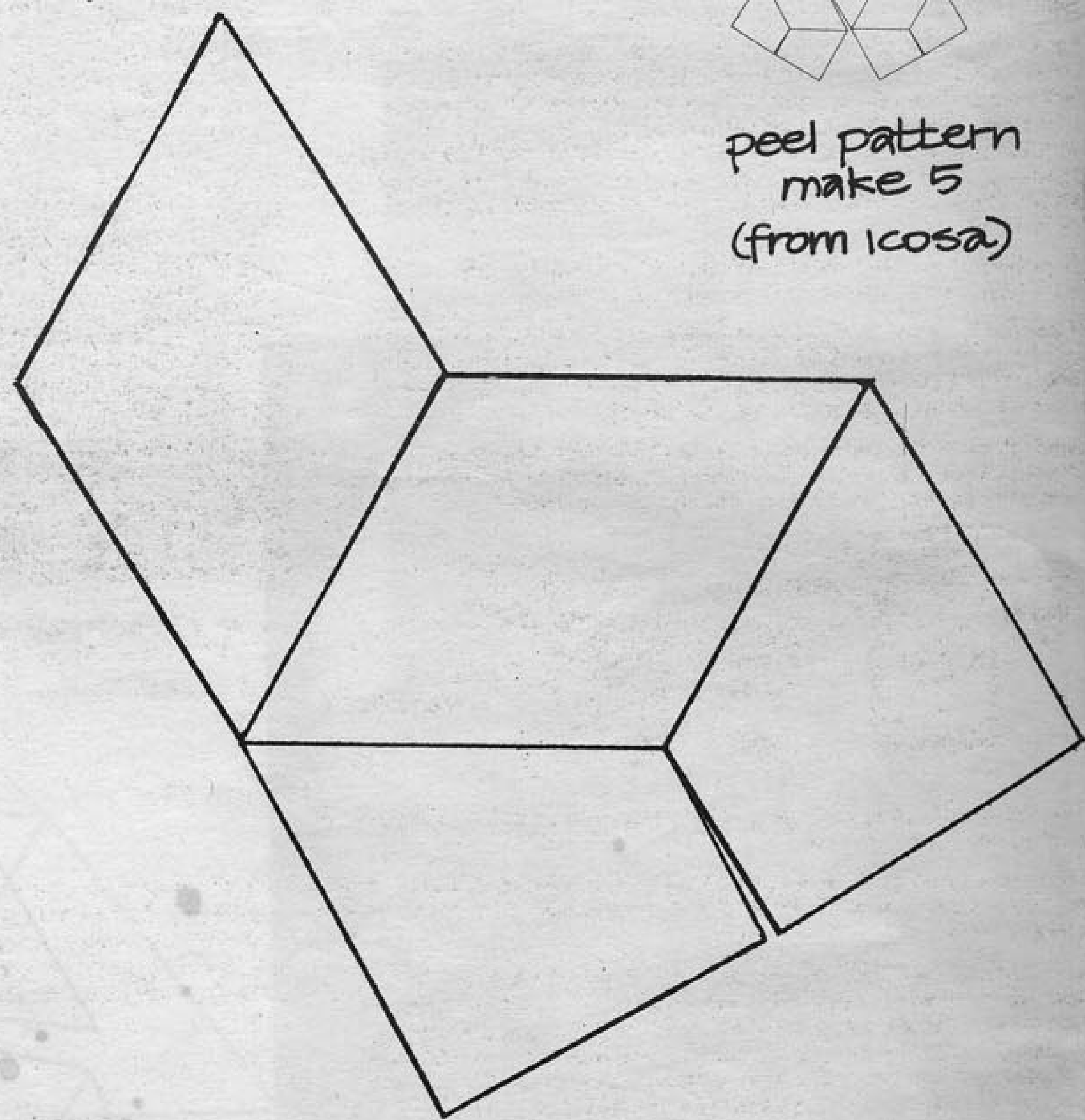
# 4v OCTAHEDRON

1/2 ellipsoid



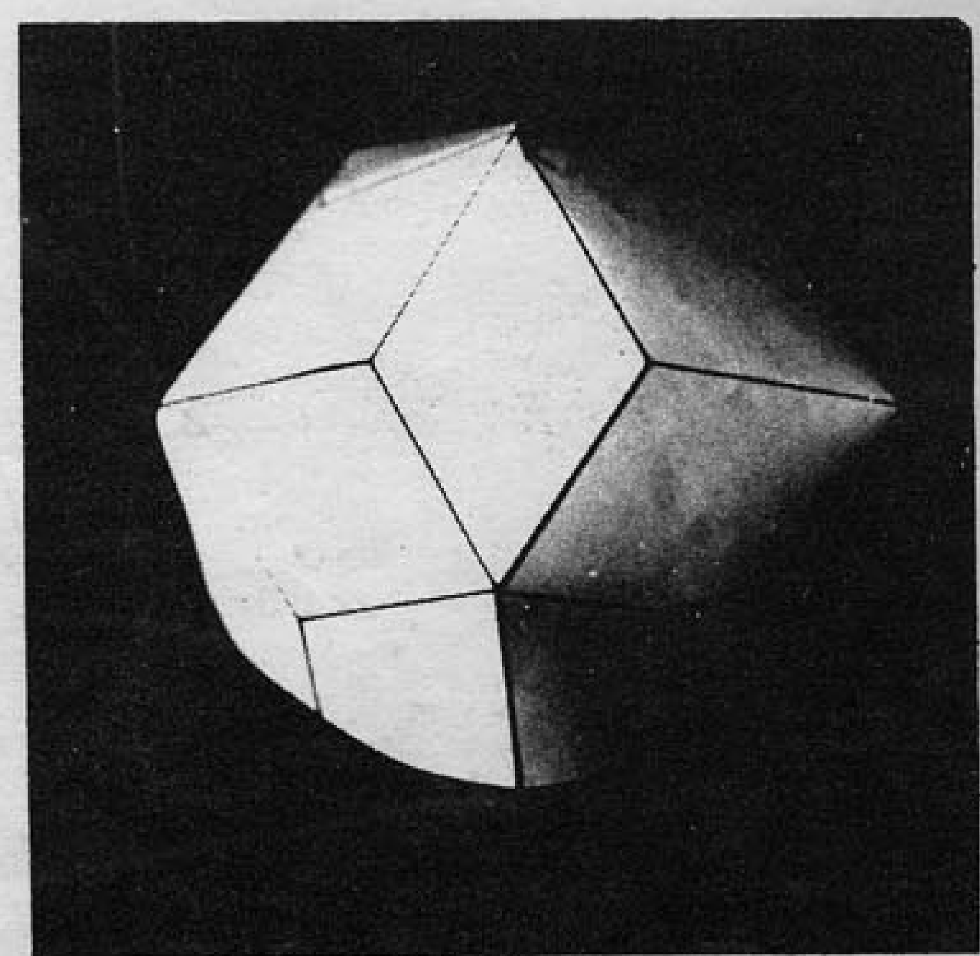
peel pattern
make 5
(from icosa)

top vertex



# TRIACONTAHEDRON

1/2 sphere



TRIA'N

# Unfast Ideas

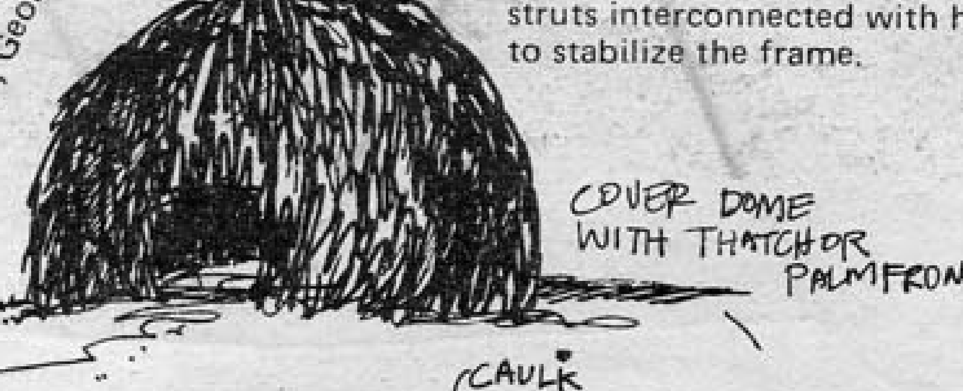
Here are random thoughts, things we've thought of in the process of building. You never know if an idea works until you try it, and when you make tests you discover facets you didn't think of before. Yet many ideas never leave the drawing board, or the patent attorney's files. Maybe what follows will give you some ideas, keep in mind that we haven't tried any of them.

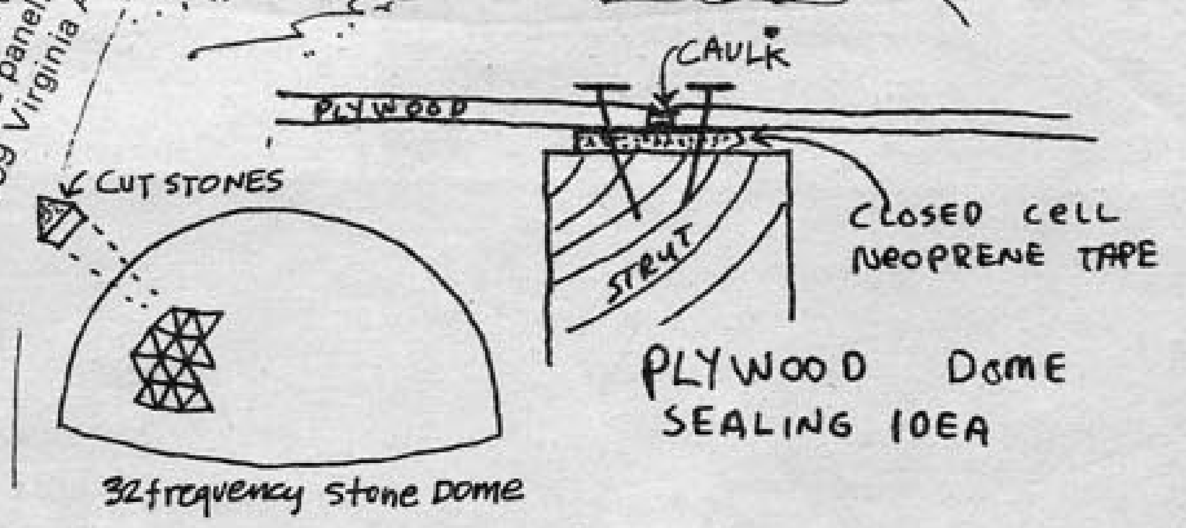
Ralph Mathews in Georgia used urethane foam in a spray can to bond styrofoam insulation to the panels of his dome. 10 cubic feet for $72 from Wooley & Co. 599 Virginia Ave. NE, Atlanta, Georgia.

Bond layers of bubble packaging material together for a flexible insulating skin.

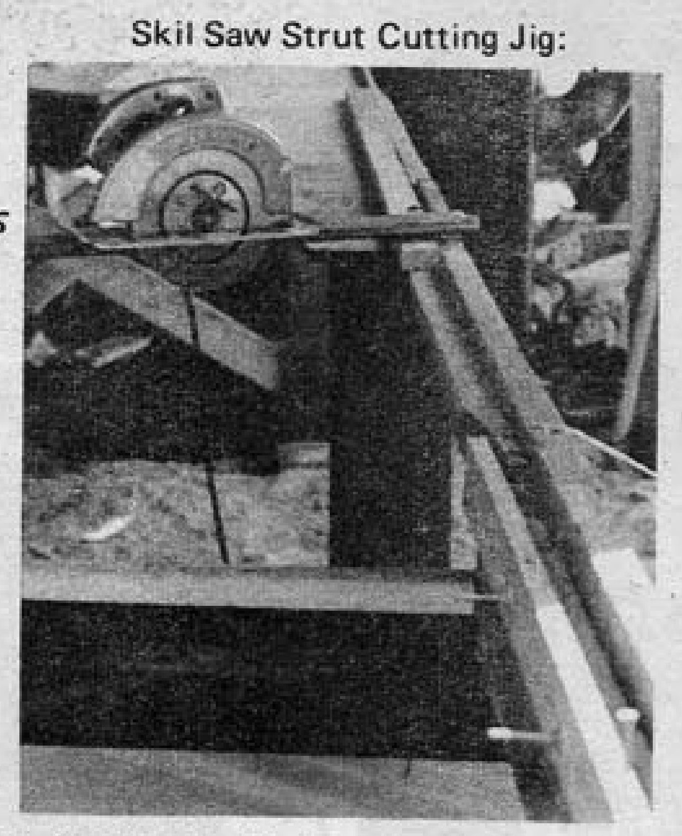
*Dow Dera-Span.* This is a foam sandwich, maybe you could use a wood frame, drop the panels down inside with the exterior skin shingled, or sealed just above the wood. See p. 98.

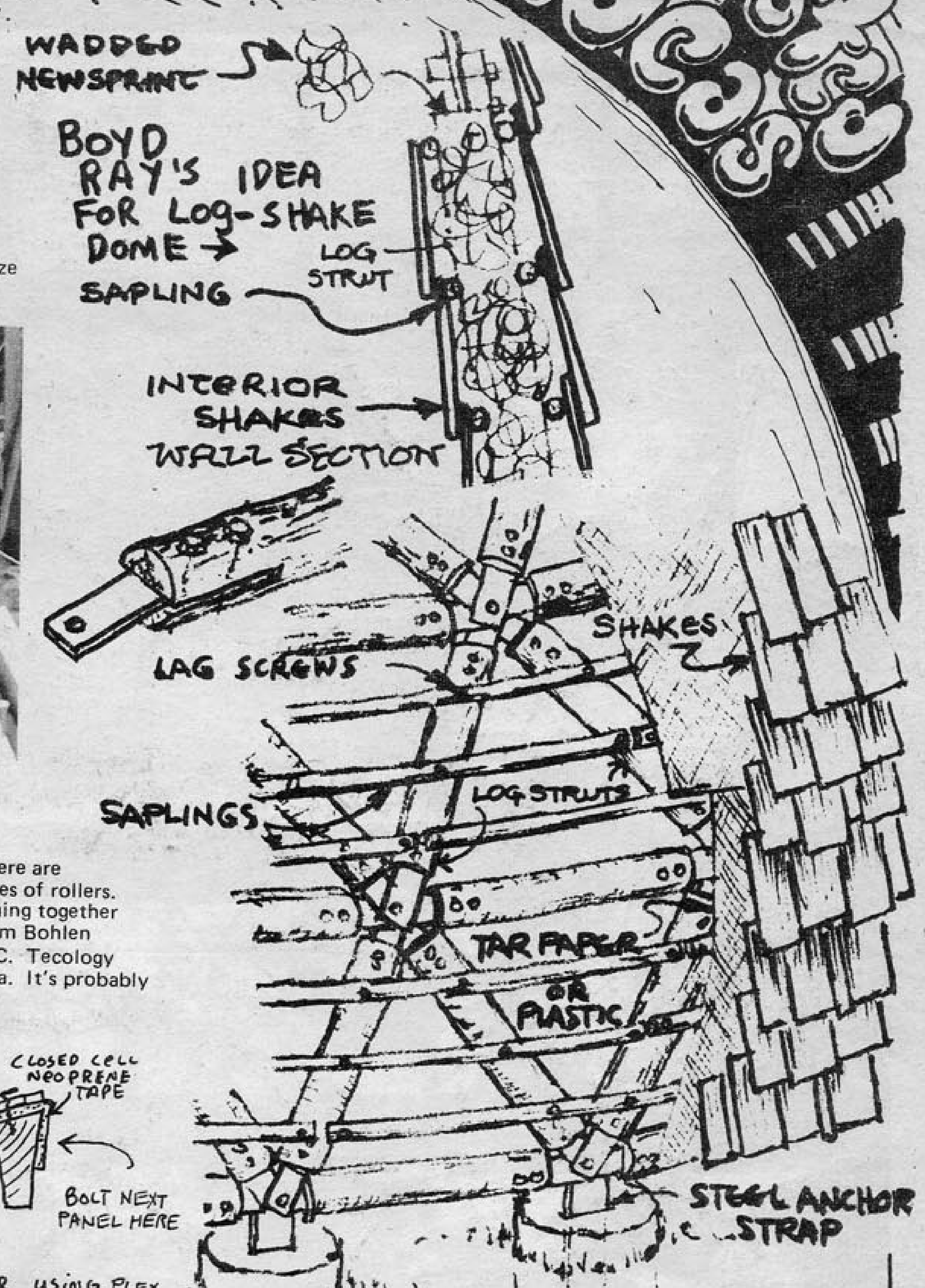
Build your frame out of platic water pipe or hose. Have all the struts interconnected with hollow hubs. Fill the water and pressurize to stabilize the frame.




Skil Saw Strut Cutting Jig:






*Variations on Aluminum Sun Dome.* Different methods of making panel frames, see pp. 29-31.

Can use aluminum angle, like Pillow Dome No. 2. Or could you use angle iron with galvanized sheet metal? Cheap, heavy.

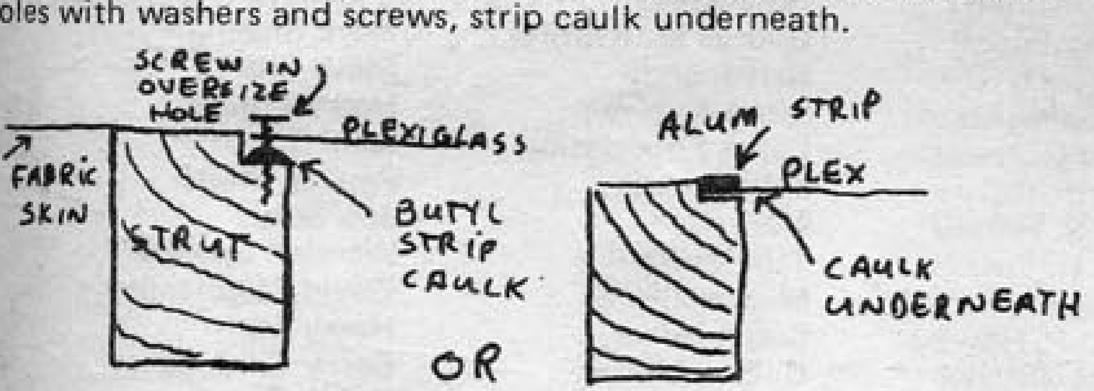
Bend polycarbonate windows over the frames.

*Variations on Muslin Foam Dome.* In putting muslin over the wood frame, we had a hard time stapling muslin to struts, and realized it would be far easier to slip a one-piece skin over the frame like a sock. If you had some way of sewing up entire skins beforehand they could be done in patterns like Peter's cut-out paper models p. 123. Then you could apply resin, which would adhere muslin to struts. Then you could cut out for windows and shoot foam.

Or instead of muslin, maybe use Herculite, or Armor Shell—waterproof fabric that doesn't need resin, if foam will stick to it.

If you can't shoot foam, put the one piece skin over frame, and use pop-in foam insulation. If the skin is translucent, you could vary the light patterns by changing insulation. I wonder if you could use burlap, resined for waterproofing.

Windows in such a dome could be made by routing out struts before putting frame up (where windows are to go), then oversized holes with washers and screws, strip caulk underneath.




Plexiglas and lexan expand and contract a great deal, you'd have to design with this in mind.

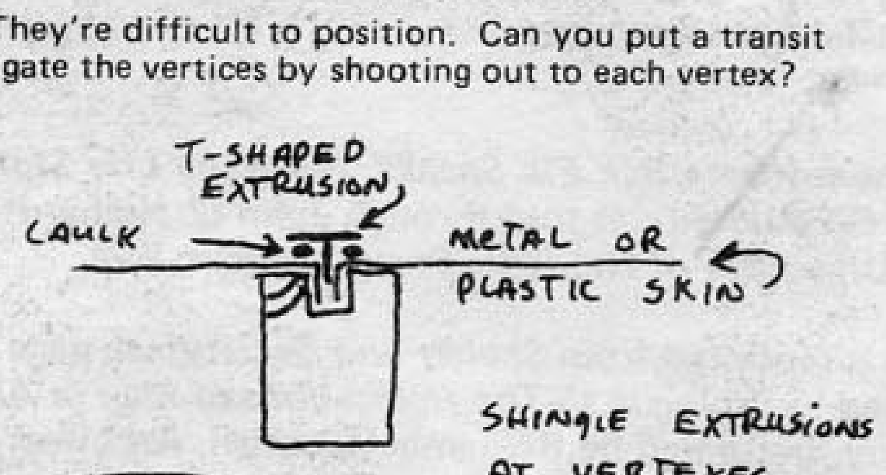
Maybe you could stretch the fabric over sun dome type frames, like painters stretch canvas, then put dome up, tape seams with 1" fiber fiberglass tape.

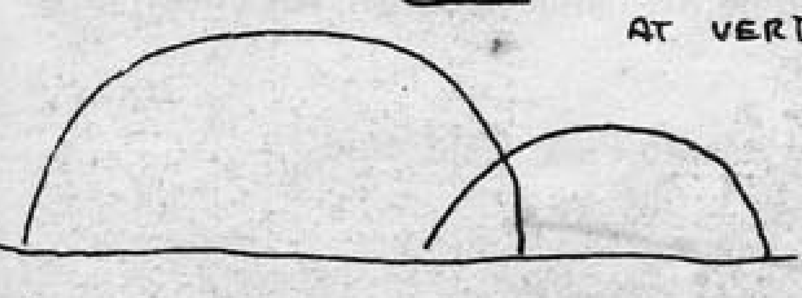
We tried tests with different cloths for covering Jonathan's dome—Defender Industries 75¢ catalog lists many different materials: Vectra cloth, Dynel, etc. Abe Shuster in Oakland has a lot of different cloths, including stuff used for nose cones. Info on both Defender and Abe on p. 86. One of the problems we found with the different fabrics was sagging when the resin is applied. Polypropylene sags less than fiberglass cloth. We thought of taking woven roving-strands of fiberglass on a spool, used for shooting chopped glass and stretching long strands of this over the entire dome frame after it's up, bisecting triangles triacon-fashion, then fabric is applied over that, and when resined, you've subdivided each triangle into 6 triangles, lessened sagging and welded the dome together with the roving.

*Float a Dome.* Build a dome houseboat, an elliptical shape would fit on a barge. Make it portable if in Sausalito so that if the city kicks out all houseboats, the dome can come up on the land.

*Hillside Domes.* They're difficult to position. Can you put a transit in the center, navigate the vertices by shooting out to each vertex?

*Jeanine's Idea:*



...terlock domes to make rooms inside.

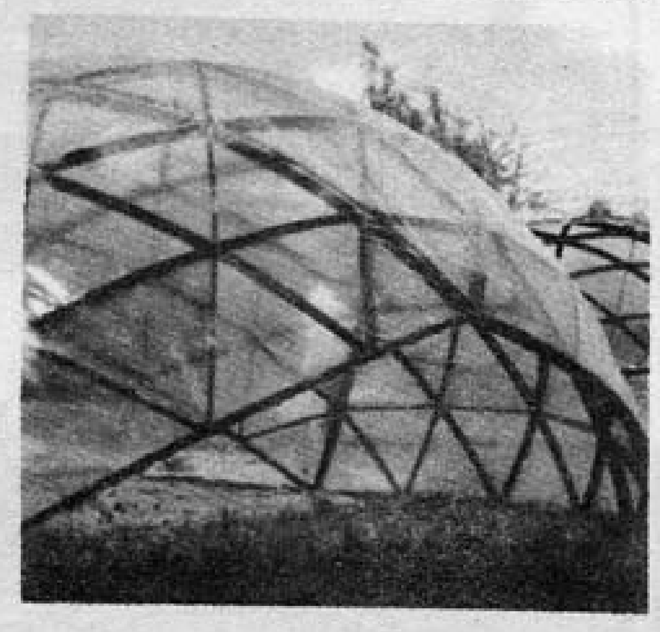
*Variations on Aluminum Triacon Dome.* Lightweight aluminum with flanges (standing seams) on outside, triangles filled with foam, then self-skinning foam.

Can use aluminum angle for windows instead of wood like 24' pillow dome.

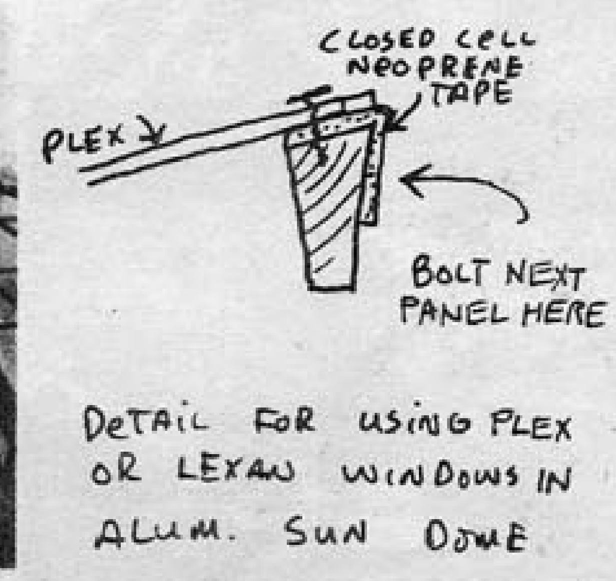
*Double skin tent, insulated with down.*

*Insulation.* Foam/Aluminum/Air Space.

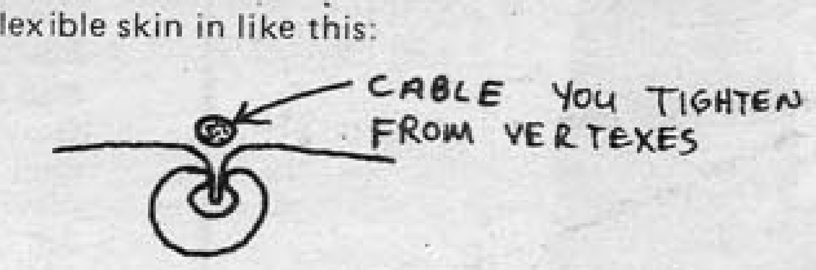
*Curved Struts.* Curved domes are very beautiful. There are companies that bend pipe by pulling it through a series of rollers. Curved wood struts have been made in Canada by gluing together layers of peeled log veneer, and Russ Chernoff and Jim Bohlen built a curved 32' triacon sphere. Their address: B. C. Tecology Centre/3504 W. 19th Ave./Vancouver 8 B. C., Canada. It's probably harder to cover a curved strut dome.



9'-8" diameter model with radius bandsawed plywood ribs built by Charles Swan, Dave Neshak, Min Maxson in 1961.

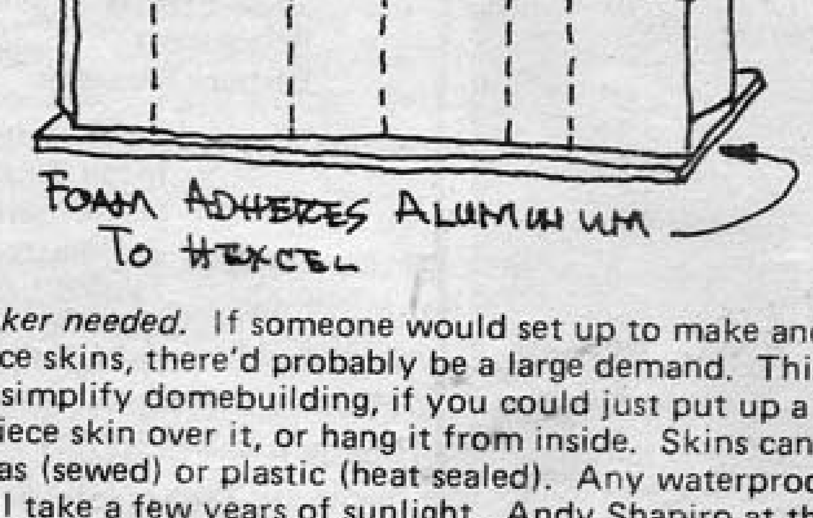



Use curved ribs, put flexible skin in like this:



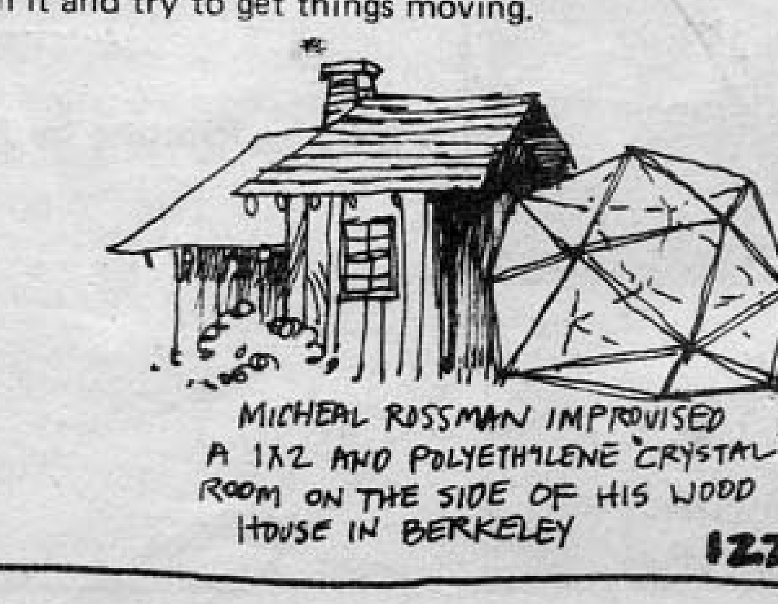

*Cottage Industry.*

*Honeycomb.* Hexagonal cell honey comb comes in paper, metal, or plastic. You could glue aluminum to it for exterior, pour polyurethane foam in cells for insulation and more rigidity. Or maybe lay hexcel on top of aluminum or plastic, pour in foam, and the foam would stick the aluminum or plastic to hexcell for outside skin.




*Skinmaker needed.* If someone would set up to make and distribute one-piece skins, there'd probably be a large demand. This would greatly simplify domebuilding, if you could just put up a frame, pull a one-piece skin over it, or hang it from inside. Skins can be made of canvas (sewed) or plastic (heat sealed). Any waterproof material that will take a few years of sunlight. Andy Shapiro at the Ant Farm was thinking of doing this.

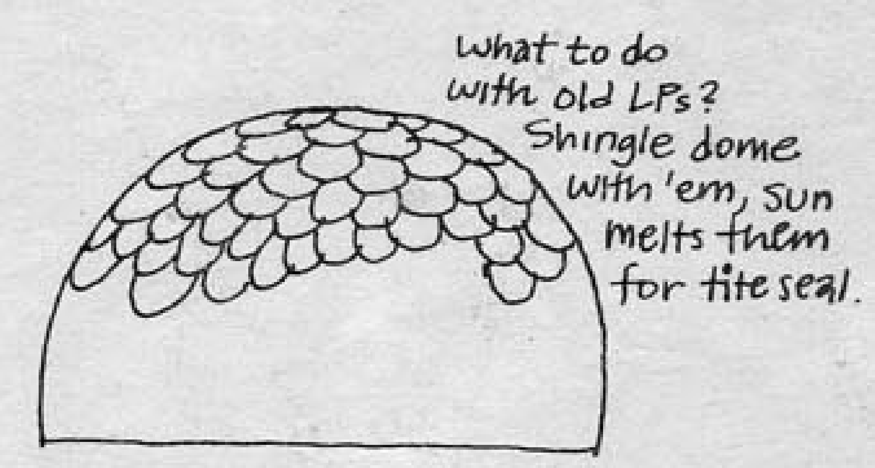
*Patents.* We learned something interesting from a patent attorney: by publishing your discovery, you preclude anyone else's patenting it, and you have a year in which to apply for the patent yourself. Patents are expensive, take time. There is material in this book that we could try to lock up with patents; we've decided we'd rather publish it and try to get things moving.



MICHEAL ROSSMAN IMPROVISED A 1X2 AND POLYETHYLENE 'CRYSTAL' ROOM ON THE SIDE OF HIS WOOD HOUSE IN BERKELEY

*Shingling Domes.* Wood shingles are difficult to put on a multi-faceted dome, as the angle changes at each triangle. There's a dome on Highway 9 in Felton, Calif. that's shingled, looks nice. However store-bought shingles are either redwood or cedar, both trees nearing extinction. You can also shingle with composition shingles—not too aesthetic, but cheap, and they work, or with roll roofing paper. Cut the paper in triangles, use 2-4 colors. This way you could use cheap plywood underneath, cover with tar paper, then roofing paper.

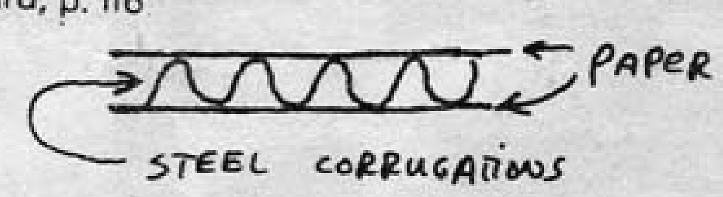
Dome of old phone books, scratched lp records.




*Inflate Whole Skin.* I believe Fuller has done this. Could be done as with vinyl pillows, all sealed together, or two skins with air in between, which would be pumped up—better than air buildings, as you don't need a blower, and there's insulation in the air space.

*Bending Lexan.* See if it can be done without fractures. Maybe use brake jaws with large radius edges. Or you could heat edges of brake to make smooth bend. Or bend as Allen Davidson describes on p. 87.

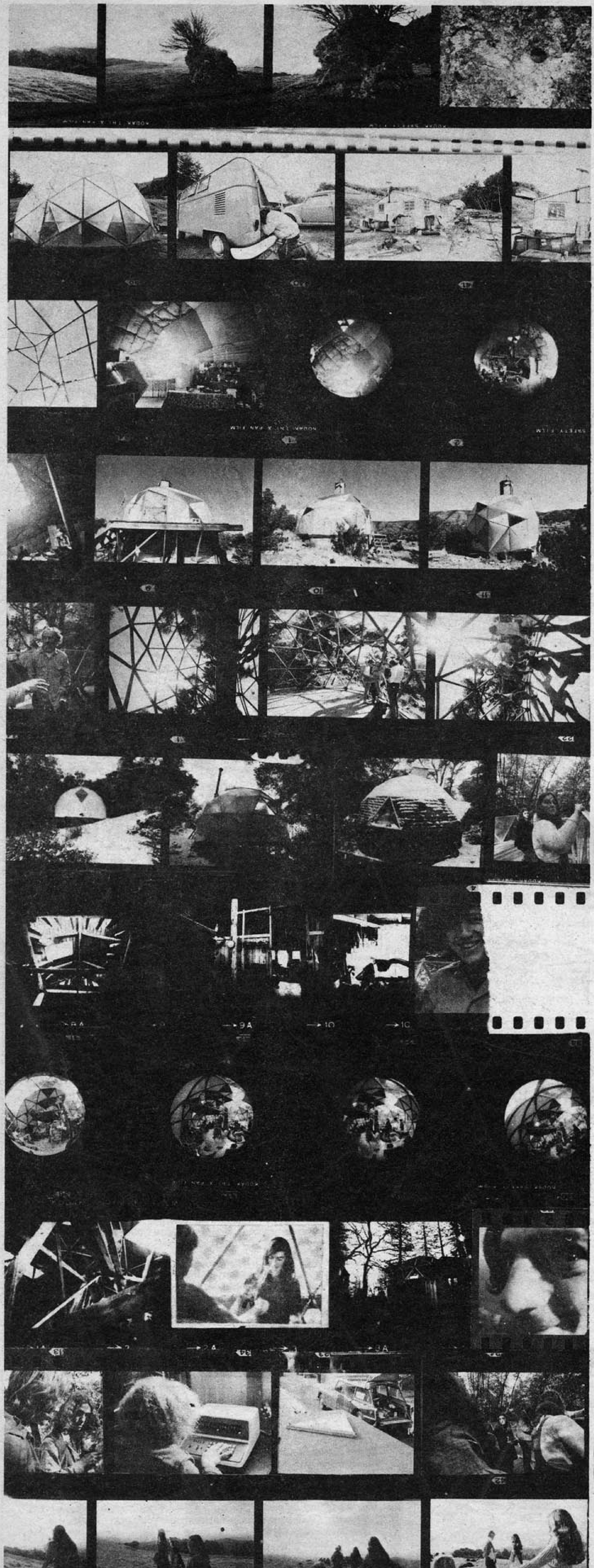
*Cardboard with Steel Corrugations.* U.S. Steel makes such stuff. One of the great problems with buildings of cardboard is that even if resined, water generally can get to spots the resin didn't hit and unhinge everything. With this stuff, having two layers of paper, with steel corrugations in between, you should be able to easily waterproof the outside paper. It's also very strong, can be scored. You can combine two or more pieces, with corrugations running in opposite directions. Put up a cardboard skin with flanges, staple together, shoot inside with foam, fiberglass tape seams afterward. See Cardboard, p. 116




*Some Random Ideas From Douglas Deeds.* Make a mold of plywood, coat with release agent, lay fiberglass in. Press rigid polyurethane foam in while resin is still wet. Mold in a linkage detail so that dome gets bolted together like sun dome.

Make a sandwich panel (for flooring or lofts) of two layers of 1/8" plywood. Glue beer cans in between the plywood. Pittsburgh Plate Glass makes an epoxy that will glue aluminum to wood, 3M probably does also. Dunk cans in epoxy and glue up.

Old newspapers can be used for panels. Make a mold, pour in thick resin, and layers of paper, make a panel with molded edges.



# DOMEBOOK 2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The quote on page one is from *Black Elk Speaks, Being the Life Story of a Holy Man of the Oglala Sioux* as told through John G. Neihardt (Flaming Rainbow), University of Nebraska Press, Lincoln, 1961.

The quote on page 13 is reprinted from *Shelter and Society* (see page 101) in which it was credited to Prologue to *The Habitations of Man in All Ages* by Viollet-Le-Duc, translated by Benjamin Bucknall, Architect, 1876.


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An unusual aspect of building a structure is that it takes such a long time to complete the physical manifestation of the one-time idea. By the time we write about what we've built and print the results, we're a long way from the ideas we started with.

Thus we're in the middle of a *process.*

A group of us found our paths intersecting in Big Sur, then at Pacific High School in 1969-71. We were all interested in exploring structure and found ourselves making communication an integral part of our cycle. Our first publication, Domebook One, was put together in two weeks with production equipment borrowed from the *Whole Earth Catalog.* Bob helped us with layout for five days. He'd come up from Santa Barbara thinking we were going to do a small mimeographed booklet. In November 1970 we mailed out 3,000 posters announcing Domebook 2 and asked for domebuilding information. (We'd kept addresses of everyone who'd ordered the first book from us by mail.) During winter months '70-71, after finished a second group of domes (pp. 26-40) we began writing, getting pictures together, assembling incoming mail. In March, Sarah, Peter, Hans, Jonathan and I packed everything into Hans' van and set off down the coast and met Bob and Jeanine at an old resort in the Santa Barbara hills. We rented 4 cabins to live in, a large room for production, had use of the lodge kitchen for cooking. We brought everything with us for production: IBM Composer, darkroom equipment, polaroid copy camera, saw horse tables, chainsaw for firewood, etc. and were set up in a day. The first night Bob and I did a general page layout, trying to arrange subjects so the book flowed like a film. This time Bob did all the layout.

Most of the book was written before we got there, but we wrote and revised a surprising amount during that month. Our system of production is fairly unique: everyone in one room, music, arguments, loud voices, incense and chaos. But out at the end of a road, we were in quiet and funky surroundings and had time and place to think about what we'd been doing. We spent long hours each day and in spite of soccer and throwing a frisbie ended up fairly physically wrecked from so much head work and sitting. The method of production — acting as your own publisher — is described in the Last Whole Earth Catalog.

O

At the moment, Pacific Domes (We're looking for a new name) is about $15,000 in debt. We made a profit of about $6,000 on Domebook One. Our printing bill for Domebook 2 was $14,006.54, our production costs about $7,800 (typewriter, rent, salaries, etc, shipping about $750). Thus the cost of each book, not counting any overhead was about $1.15. We end up getting a net of about $1.50 after percentage to Random House and our agent. This leaves us 35c per book. We'll have a higher percentage profit on this printing of 40,000 copies. So far our expenses have been $17,341.21 printing, $2200 shipping, about $400 production for revisions.

The financial picture leads us to the realization we need another source of income. We might get a grant but don't have the knowledge or the connections to apply for one. One of our hopes is to find land, build living structures, set up production facilities, have a place to test some things such as new structures and Hans' wind generator — a place to live and work. We might lease the land for a specific period and work out an arrangement with the owner to leave the structures behind when we move on. We can also send people out to help start specific building projects.

O

Our work from here on will be on *shelter,* not just domes. We need incoming information on any subject related to the work we're doing. We'd like to find people willing to pursue various projects such as recycled building materials, solar heating, or an investigation into the manufacturing processes of, for example, polyurethane foam vs. cement in terms of pollution caused by each. We need lawyers and engineers to help us loosen up building codes. If you wish to help let us know and we'll contact you when we start getting ready to do the next publication.

O