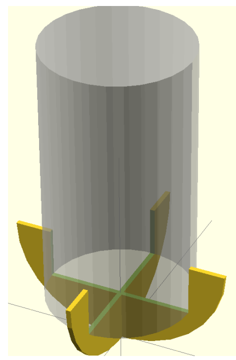
Plane talk on SudiBalls

Tom Conlin 2013 May

Several years ago, David Davis founder of the Oregon Scope Werks asked me to think about a mount for a 1.5m F-3(ish) tessellated mirror he was making. It was not intended as a visual scope but would have a single central mast with an IR instrument package near prime focus. The requirements only called for it pointing 30 degrees off of zenith, being self contained on a utility trailer frame to be pulled by car, having motorized pointing if possible (low accuracy okay) and as always, dirt cheap.

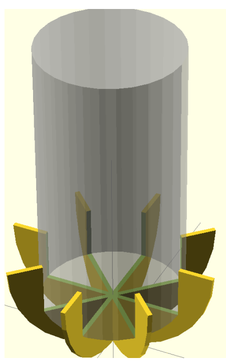
Being saturated with work, grad school & life I could not really do much about it but it was a more interesting problem than many I had to wade through so it did get some attention especially when I was supposed to be doing something else. David always liked the simplicity of the ring base on my Ball Scope. I had grabbed a ring base as a temporary expedient before I made a Polar Axle drive... Well that was closer to a decade ago than not and I'm still using it so I guess I must like it too. The trouble for David's problem is even if you could get a light enough eight foot ball or hemisphere, the cost would be prohibitive. No, this has to be made from everyday material available in bulk.



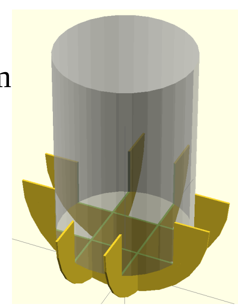
Like sheets of plywood!

So we cut 4'x8' sheets into half circles, cut out the top middle for the mirror, crisscross them and boom! we're done.

However it would be kind of spindly so a lot of braces would be needed. And, there is not much support between the rockers so ... we should try adding in more radial sections.



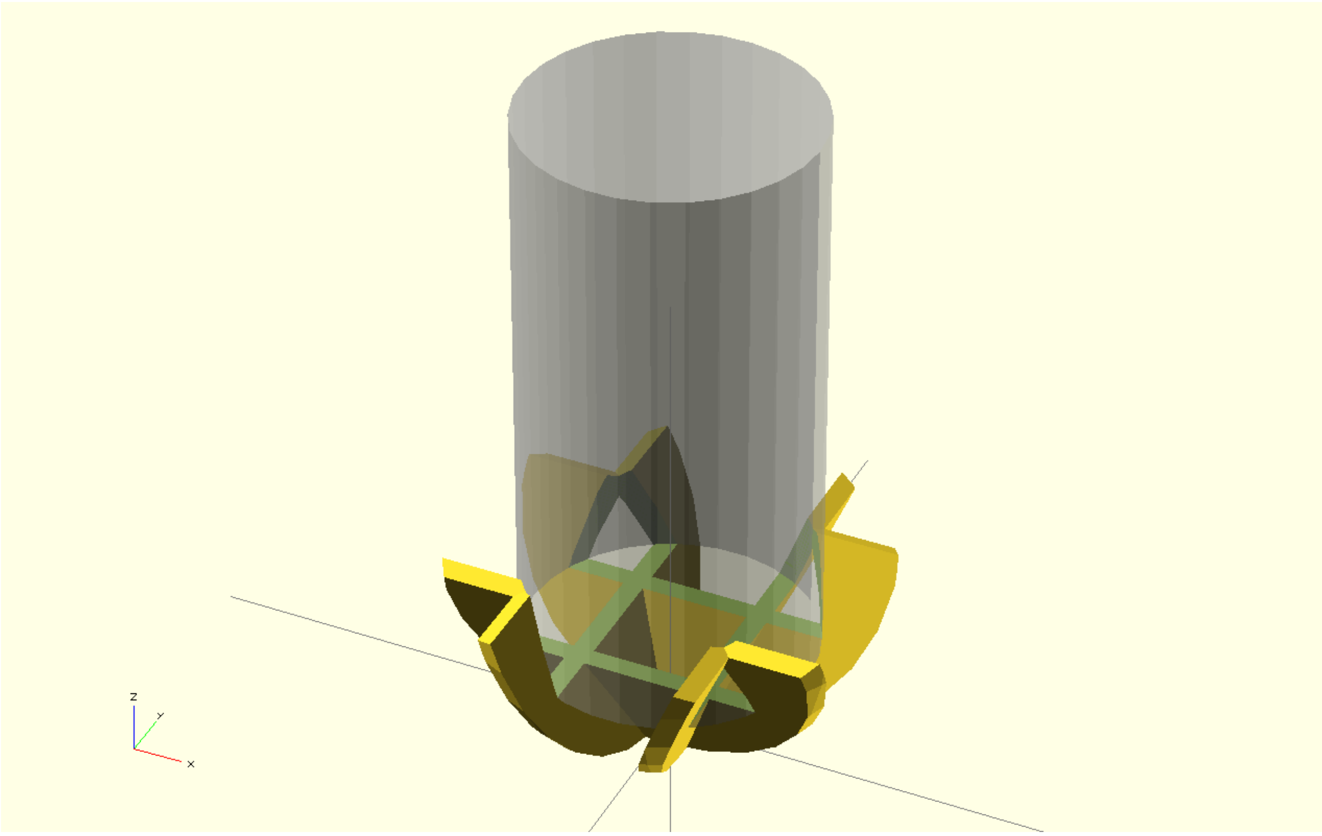
This is better, but puts extra material in the center where it is not needed and increases the number of spindly members without actually reducing their spindlyness. It would be nice to take those same four sheets of plywood and redistribute them so they did more good, spread them out like rocking chair runners in orthogonal directions.



This sort of looks like an improvement but there is a very serious problem in that the edges of the runners do not all touch the surface of the *same* sphere. They would form a surface of four nearly overlapping spheres so it would be a bit “wubbley”. Drat! Fixing that as is would mean generating a non circular curve on the runners and we at the Werks do tend towards the simple.

Something here does not make any sense. The sheets are half circles; **every** circle, half or not which is not larger than a sphere **can** fit within perfectly, touching along the entire circumference . These half circles surely cannot be larger than the sphere they are creating so what gives?

The answer can be seen as placement. Yes we can fit any smaller circle in a sphere perfectly but can not always choose where, i.e. we can't make it cover the entire equator if it is not big enough. By forcing the rockers to be parallel at right angles we are trying to have a sphere with multiple parallel equators. Let's not do that. Instead of leaving the sheets parallel, tilt them outwards from bottom center. Once we do this, the possibilities become endless.



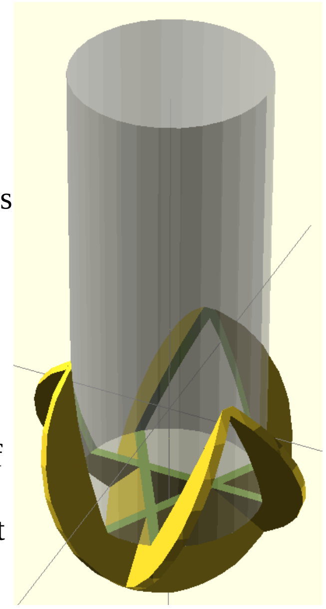
A note before we go on. The Edges, OMG! they are compound curves! Yes, but *they are all exactly the same everywhere!* Both parts of the compound curves are circular, long-way is the semicircle's radius, short-way the radius of the effective sphere. In fact cutting the semicircle with a router as a compass with a correct profile bit would generate the **perfect** shape. Short of that, a router with a straight bit angled to the tangent of the sphere at the center of the edge would be a fair approximation, as would rounding the corners over so the edges mainly contacted in the middle. Or even better may be applying a strip of edging with material and profile of your choice as Chuck Lott did building the first model (David was muttering about magnetic levitation drives on the edges). Even if you measured with a yardstick marked with chalk and cut with an axe there is still hope for your runners because if you apply a bit of sandpaper to the inside of a ring, set the mount on it and swirl it around randomly you will generate the sphere you need, including the compound curve on the edges.

With this configuration the edges are redistributed so they are not redundantly covering the bottom and the spindlyness and fiddly bracing problems are well addressed by the ends of the runners supporting one another at right angles for triangulation and bracing. I call the requirements for this specific mount done. But who am I to leave well enough alone?

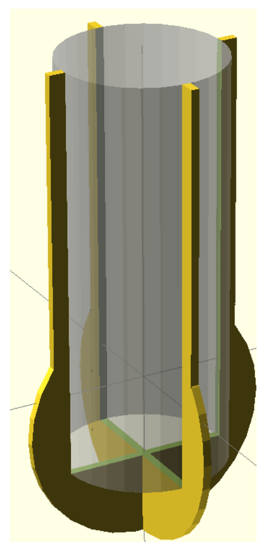
From geometry, two non-parallel planes intersect as a line, and three planes, at least as a point. In the last picture the intersection point for all the planes is below the ball. A natural question is: what if the intersection point was moved up to be inside the ball? Or above it?

And while we are at it, shouldn't we only *need* three planes? The answer is that number of planes the position of the intersection point (nominally along the optical axis) and the tilt the planes allow for infinite variations on this theme. n.b. Not all configurations work.

Here is an early one I like.

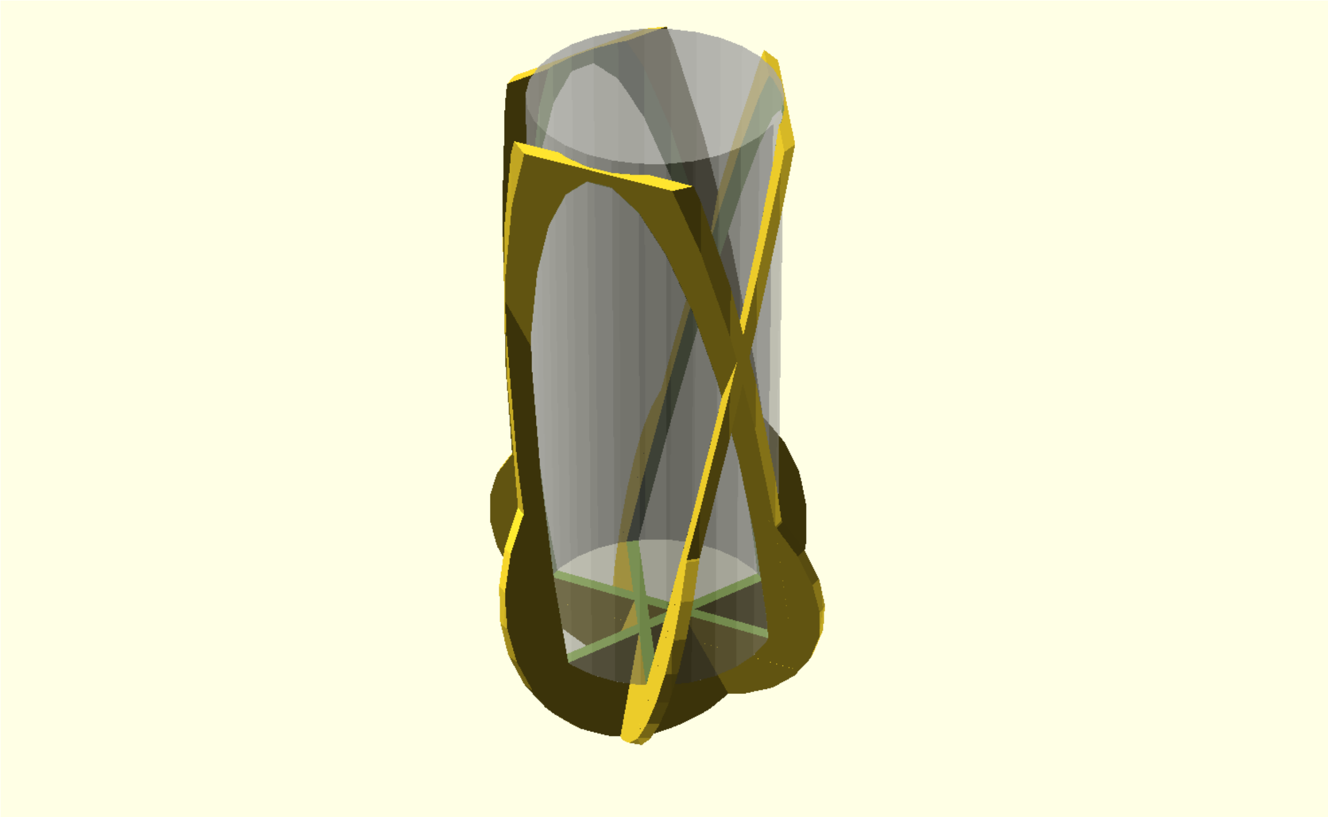


This is what I tried to verbally explain to David at some point a couple of years ago (we live ~100 mi apart so some communication can be slow). I'm sure it was a vague description, no sketches or anything but me just babbling about what I saw in my head. And that was that. I have a reminder on my whiteboard to build a model for David but it so old now it won't erase anymore. Fast forward a couple of years and David explains his recollection of my explanation to Chuck Lott while fishing. I doubt there was much sketching there either but the basic idea that flat circles can be used in place of a sphere for a ball scope sitting in a ring did. And within hours Chuck had built a functional model, and within a days a working scope. Then David built one using four (or two) semicircles instead of three.

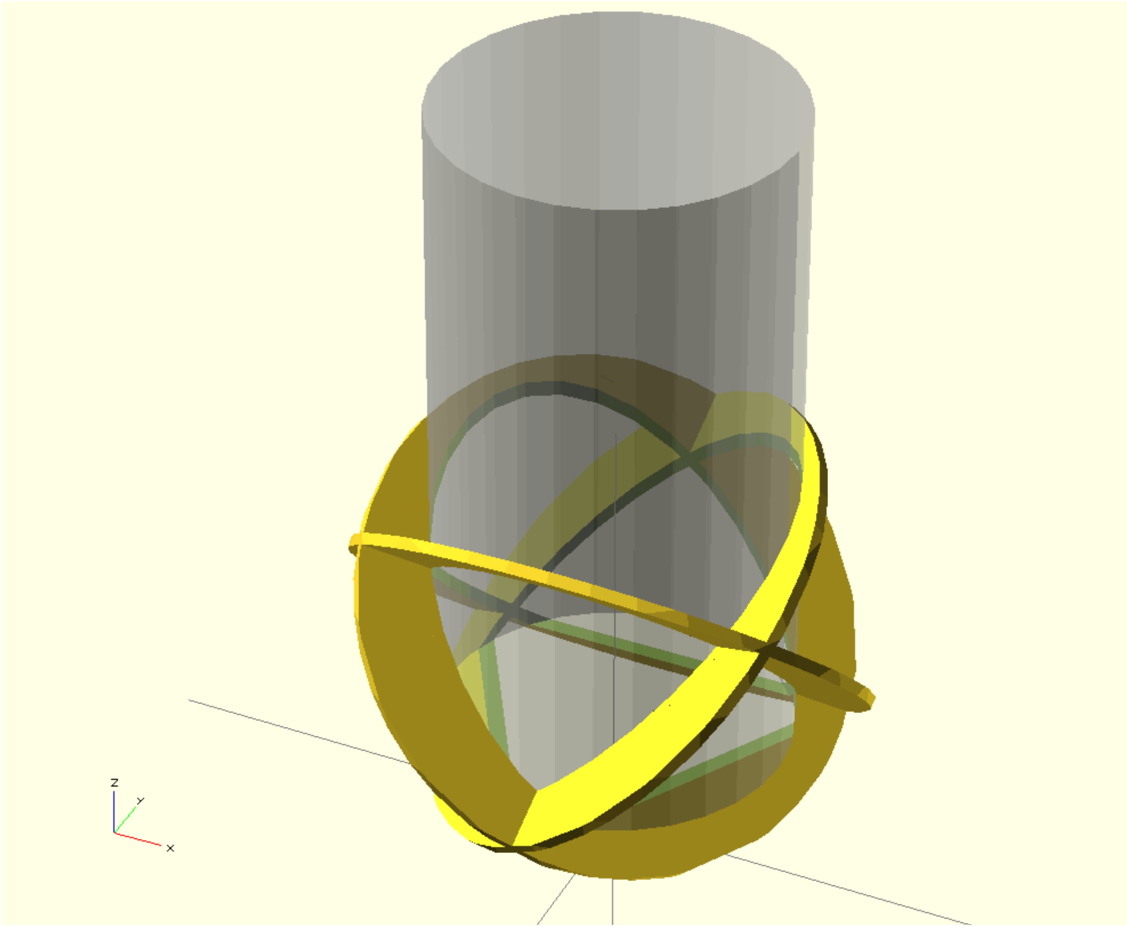
Chuck's scope is sort of like this:  and David's: 

With David's crossed semicircles bringing us right back to where we started on the first page but with the wonderful addition of integrated poles. So how are these two at all the same as the ones above? They look absolutely nothing alike! Remember two non parallel planes intersect as a line and three at least as a point? Well that third plane *can* also intersect along the same line as the first two in which case none of the planes can have any tilt and an intersection point has no meaning as it is every point along the line. This special case makes it easy for the planes to intersect the sphere in a meaningful way (impossible not to as they are always on some equator) by trading off properties of self support via triangulation, and the targeted distribution of edges. At this point I think it is safe to say Chuck and David have proven this is a viable way to build (un-driven) “balls” for scopes on rings much smaller than the original 1.5 meters specified.

Putting it all together, given a reasonable ball scope “model” (in a mathematical sense) ; short F-ratio, ball about 1.5 times mirror diameter, the F-ratio, an OTA “thickness”, you can vary just three parameters: number of planes, “height” of intersection, and angle of tilt to generate a bewildering array of designs including all shown here (sans the wubbely sphere). Since they are more fun to look at than read about let's do that.

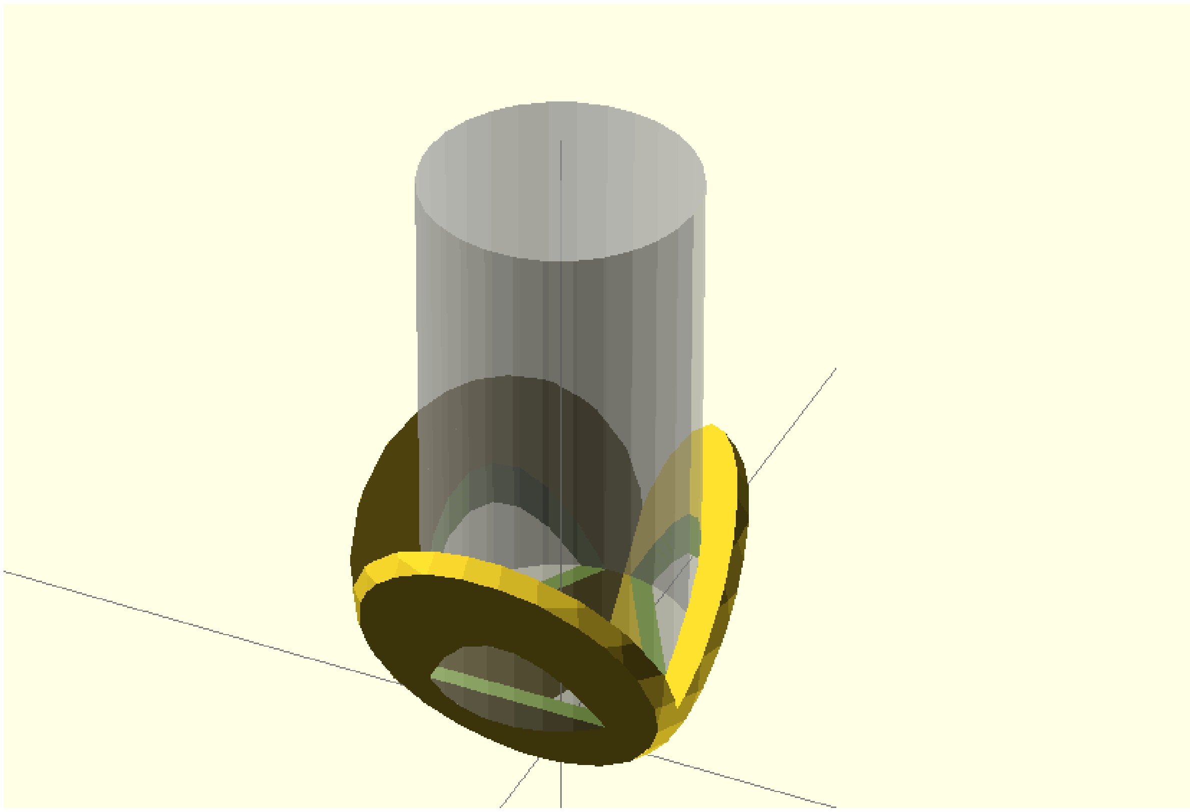


This is why David's inclusion of the poles integrated onto the semi circle is so wonderful,
tilted poles are trusses!



There is more than one way to gain rigidity for the rockers. This one reminds me of atoms.

When this tricycle popped up I had a faint recollection of seeing something like it in an old telescope book somewhere.



Obviously, this is all just geometry and as my nigh recollection of this tricycle ball scope shows, all must have been done sometime before and will likely all be redone again and again.

So without further ado “have at it”.

There is plenty more to do finding neat ways to interlock the planes. I can't wait to see the first one that disassembles to store flat. Ya know with enough planes, the truss becomes lattice and so on and on. Hopefully we will see some more of these functionally and aesthetically beautiful scopes in the near future.

What are they to be called is also a good question. David liked “Pseudo spheres” but some pointed out that implied 'not good enough'. Chuck called his first version a Clover ball for a three leaf clover. I'm obviously content with a bad pun between Pseudo Ball and Suitable (I know, woosh). But in the end, it will still be a rose by any true name.

All of these images were generated by myself with a program called openSCAD (Script Cad) which is what some of my 3D printer buddies are using. Being oriented towards 3D printing it may not have been the best choice to generate the layout of the planes for construction but the day spent learning to produce these images and playing with the model was thoroughly enjoyable.

Postscript ;

David's other “would be nice” is a drive of some sort. For that my thought is: driven cables running down from the equator under the ball and back up to the equator 180 degrees around the sphere.   With another cable doing the same 90 degrees around from the first crossing at bottom dead center. Thus the ball is pulled down onto the ring (goodbye balance problems). With the cable ends attached so they are able to rotate about the axis they are pulling in, the other cable is free to change its angle without effecting the first. I mention staying on the equator for simplicity, but any cable configuration which clears the mount could be made to work (i.e. tangent to a higher latitude).

Different topic:
A point deliberately not brought up previously is breaking symmetry by moving the intersection point of the planes off the optical axis. This promises all sorts of trouble we can get into. Maybe an eccentric mount with a rotating secondary for a constant eyepiece height.

I need to thank David Davis for being audacious enough to ask his set of questions in the first place. And Chuck Lott for the ferocity with which he brings the faintest spark of an idea into splendid reality. And I thank my long suffering wife Charlotte for almost making it look as though I could write.

This documents home: http://ix.cs.uoregon.edu/~tomc/Hobbies/Astronomy/ATM/SudiBall.pdf

Questions may be directed to sudiball360@gmail.com

Lastly, the next page is some code to generate these SudiBalls in openSCAD for hours of fun!
Also found on github without formatting issues: https://github.com/TomConlin/Sudiball

```
// OpenSCAD  file  for  generating  SudiBalls
// design parameters
planes=3;           //  3,4...  (2 for a dob like rockers)
tilt=9;             // +/- angles in deg (zero for Chuck & David's)
intersect=-45;      // +/- units from bottom of ball

// ota parameters
ota_id=30;          // ~ mirror
F_ratio=3;          // determines OTA length
thickness=1;        // semicircle & truss thickness
factor=1.5;         // mirror to ball ratio

////////////////////////
// derived variables (don't need to touch them but whatever)
ota_ir=ota_id/2;
ota_or=ota_ir+thickness;
ball_r=ota_ir*factor;
delta=360/planes;
///////////////////////

// spit out the planes
module sheet (w, t, h, r) {
     translate([0,0,-intersect])
          rotate(a=[tilt,0,r])
               translate([0,0,h/2+intersect])
                    cube(size=[w,t,h],center=true);
}

/// the model
difference() {
     intersection() {
          union() {
               translate([0,0,ball_r]) sphere(ball_r,center=true);
               translate([0,0,ball_r])
cylinder(r=ota_or,h=F_ratio*ota_id);
          }
          union() {
               for(rot=[0:delta:360])
                    sheet(2*ball_r,thickness,4*ball_r, rot);
          }
     }
     translate([0,0,ball_r/2])
          cylinder(r=ota_ir,h=F_ratio*ota_id);
}

// show primary light path
translate([0,0,ball_r/2])
     %cylinder(r=ota_ir,h=F_ratio*ota_id);
```