PELLEXTRUDER: IS IT POSSIBLE TO 3D-PRINT FROM PLASTIC PELLETS?

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THE ABDUS SALAM INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

Best ideas come from real needs

- Which is the biggest limitation of FDM 3D printing technology? The most common answer: the **filament** (availability, cost, characteristics)
- What if we could 3D print using raw plastic pellets/granules (maybe recycled from waste)...???
- Many have tried, and there are even some solutions — within a limited scope (only for "spiralize" print).

From the need to the idea

- We analyzed what has been tested by others:
  - Filament extruders with Auger screw (*Archimedes' coclea*)
  - Issues with Auger screw (*non volumetric* pump)
  - Do *volumetric* pumps exist?

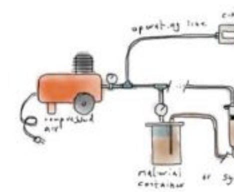
repeatability is low. One solution would be to maintain a constant pressure level and throttle the material flow at the nozzle. There are various industrial valves that do just this, and these could be easy to replicate. F@H's valve tool does this by using an off-the-shelf valve between the syringe and the nozzle. The vintage RepRap Support Extruder 1.0 uses a similar method.

Honestly, most people using DAPEs (mainly for ceramics) have stopped using electronic valves altogether and designed around the problem by creating objects that can be printed in one continuous action without the need for the extruder to jump from one place to another. Pressure is plugged in at the start of the print and released at the end, again a very hands-on approach. As with the Stepper Driven Syringe Pump, If you don't mind manually controlling the extrusion process, DAPEs are a great way to start exploring paste extrusion, especially for printing ceramics and other large volume materials.

3) Positive Displacement Extruders

So we want the best of both worlds don't we? We want to move the syringe out of the extruder, and a stepper motor would be lovely for compatibility, we want a pure volumetric or metered system and we don't want to control the extrusion by pushing all our paste material back and forth but rather control the flow close to the nozzle.

Enter the volumetric or positive displacement pump. Frustrated by the first two principles as a starting point for an extruder worthy to sit next to your high quality filament extruder I started to look at the various ways in which industry, and more specifically the dispensing industry, tackled this problem and started digging through countless websites and books.



From wikipedia: A positive displaceme[nt] pump makes a fluid move by trapping a fix[ed] amount and forcing (displacing) that trapp[ed] volume into the discharge pipe.

So the key here in the definition is the 'trapping a fixed amount' part. Each rotation of the pump mechanism traps a specific volume of material and sends it [to] the exit of the pump, the nozzle. If a ste[p]per motor drives this, we have a system [in] which we know that X amount of motor st[eps] results in Y amount of extruded volum[e]. You place this pump as close as possibl[e to] the nozzle and let it 'pull in' the materia[l] from a feed line in exactly the same way your filament extruder pulls in the filam[ent] right before the nozzle.

The only difference is that we don't have a nice roll of filament but a messy [...] of paste in a reservoir. So there is the ne[ed] for an external reservoir. In case of a ru[nny] fluid like a molten chocolate one could u[se] a gravity feed system (the material flow[s to] the pump by gravity when the reservoir [is] above the extruder) but more often than [not] we will need to pressurize the reservoir. [The] easiest way is by air pressure. Yes, that [un]controllable thing we rejected above. In [...] case we apply more than enough pressu[re]

Paste Extrusion ■ Feature

which still holds: *"Positive displacement implies that a specific volume of material is displaced within a specific mechanical actuation. Positive displacement is not influenced by changes in temperature or viscosity. The Archimedes screw pump is very consistent, but this consistency depends on the viscosity and flow characteristics of the material. Archimedes screws have been marketed as positive displacement pumps, but viscosity metering pumps is a better definition."*

True positive displacement pumps should produce the same flow at any given speed no matter the discharge pressure. And this is where the last system comes into view, the Moineau pump. From the surface this pumps looks pretty much the same as an auger pump but the geometry of the auger (the rotor) and housing (the stator) are a bit more complicated. In a Moineau there is no continued path down the rotor but several sealed cavities between rotor and stator which progress down when the rotor is turned, hence it's other common name: progressing cavity pump. Every cavity has a known volume so with each rotation a specific volume is being discharged from one or more cavities. The intricate geometry ensures that the cavities alternate to avoid pulsations in the extrusion.

The only influence the input pressure has, is that it needs to be high enough to feed the material in the pump but not to high that it would leak past the rotor-stator seal and this is often a wide range. Other beneficial characteristics is that the Moineau is very well suited for pastes and particle filled slurries. So it's designed for extreme applications like in the oil drilling industry but also very well suited for less demanding applications.

I never thought it would be possible (at least not for me) to design a printable Moineau pump but early 2012 Tomi Salo posted a Moineau stepper extruder on

Tomi Salo Moineau
photo by Tomi Salo

Unfold Moineau
photo by Unfold

Thingiverse designed in OpenSCAD and based on the basic parametric rotor and stator geometry by Emmett Lalish. Tomi's design is a gravity feed design and not suitable for working with materials under pressure. I made a quick and dirty update to seal all the parts and stepper shaft and tested the updated extruder with clay. In the initial test, which you can find on YouTube, the extruder performed very consistent with instant start and stop and responsive ramping.

The extruder's drive mechanism and shafts failed rather quickly though because of the substantial torque needed to pump

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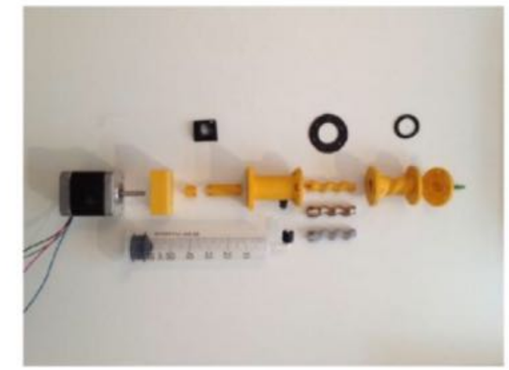

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PROJECT

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ISSUE 3 PAGES 26-40

DATE **MARCH 2014**

CLIENT **BY DRIES VERBRUGGEN**

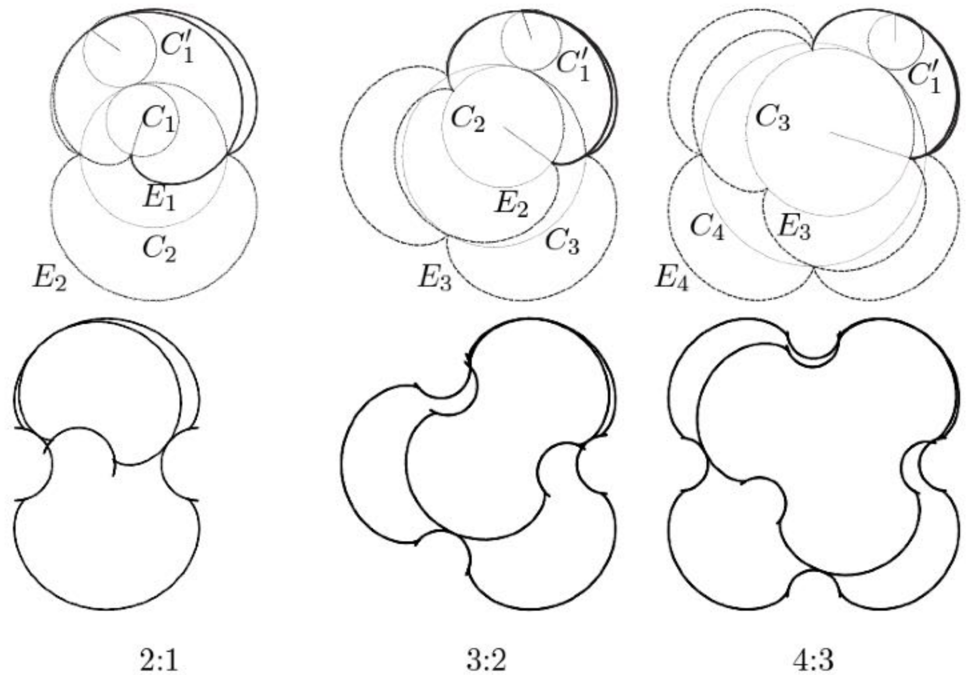

Fig. 4. Above the $n+1{:}n$ epi-cycloid construction for $n = 1, 2, 3$, below offsets.

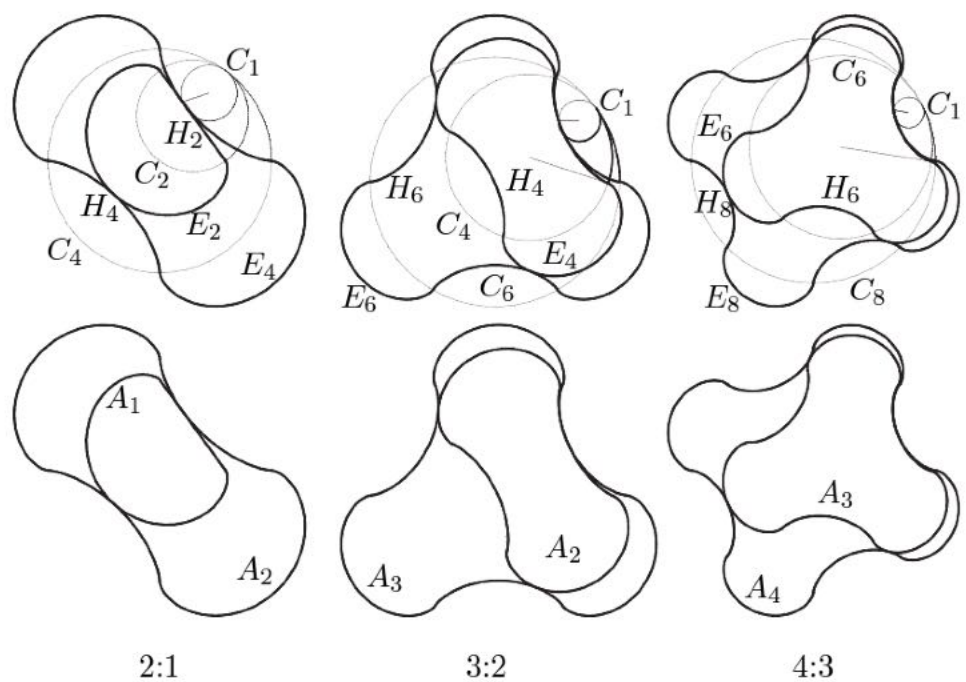

Fig. 5. The construction consisting of alternating arcs of hypo- and epi-cycloids.

2.3 The $n+1{:}n$ hypo-epi-cycloid construction

The geometry of the Moineau pump

Jens Gravesen

Technical University of Denmark, Department of Mathematics

26 March 2008

Abstract

The Moineau pump was invented in 1931 by the French engineer René Moineau and exhibits an intriguing geometry. The original design is based on hypo- and epi-cycloids and all except one design has either cusps or less severe inflexion points with infinite curvature. By using the support function to represent planar curves it is possible to make an explicit analysis of a general design and we can show that points of infinite curvature are unavoidable.

Key words: Moineau pump, envelope, support function.

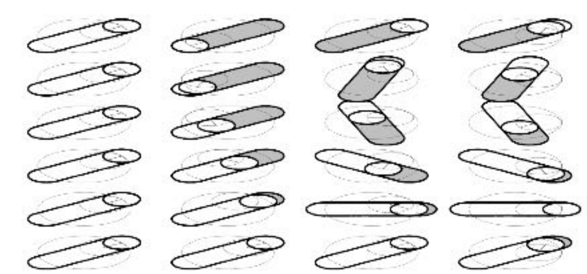

Fig. 2. The construction of the pump is illustrated in the first three pictures and the pumping in the last two pictures.

the thick "rounded rectangles", the rotor is formed by the thick small circles, and the space in between forms two series of pump chambers. In Fig. 2 the horizontal sections in one of the pump chambers are coloured in gray but only a portion corresponding to half the height of a pump chamber is shown, (any other portion can be found by symmetry). As all copies of C_1 now are above each other they form a cylinder as do the copies of C_2. If the C_1 cylinder now rolls inside the C_2 cylinder the thick small circles moves back and forth inside the "rounded rectangles". As we see from the difference between the third and the last picture this has same effect as a vertical translation followed by a rotation, i.e., the pump chambers are moved up (or down) by a screw motion. For more pictures and animations, see [8,9].

2.1 The $n+1{:}n$ hypo-cycloid construction

Consider Fig. 3. We have three circles C_1, C_n and C_{n+1} with radii 1, n, and $n+1$ respectively. Rolling C_1 inside C_n and C_{n+1} produces the two hypo-cycloids H_n and H_{n+1} respectively. Now consider the motion generated by letting C_n roll

THE GEOMETRY OF THE MOINEAU PUMP

MATHEMATICAL PAPER BY JENS GRAVESEN (TU DENMARK), MARCH 2008

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Spherical curves for the design of conical Moineau pumps

Jens Gravesen

Department of Mathematics

Technical University of Denmark

for Grundfos

Background

The Moineau pump is an invention from 1931 (US-Patent no. 1 892 217) by the French engineer René Moineau.

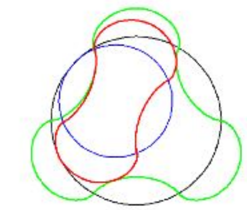
In the photo to the right models of the classical 2:1 hypo-cycloid construction and the 3:2 epi- hypo-cycloid construction are shown. In both cases the stator is to the left and the rotor is to the right. The oddly shaped object in front of the 2:1 hypocycloid construction is a model of the pump chamber.

The rotor is moved inside the stator by an eccentric motion that can be generated by letting a cylinder of radius n-1 roll inside a cylinder of radius n.

During the motion a series of closed pump champers are moved up (or down) and in contrast to centrifugal pumps the speed and thereby the flow can be as small as you like. The pump chambers have constant volume, and this makes the pumps ideally suited for incompressible fluids.

The classical cylindrical Moineau pumps

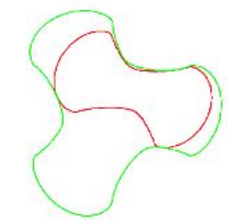
The geometry of the pumps seems quite complicated but it helps that each horizontal section looks exactly the same. A horizontal plane intersect the pump in two closed curves that are moved relative to each other by the motion generated by letting a circle of radius n-1 roll inside a circle of radius n.



The (green) stator is the envelope generated by the motion of the (red) rotor. The two closed curves forms n chambers that during the motion open and close.
The classical designs are based on hypo- and epi-cycloids and are described in the table below.

Curves	Number of "teeths" on the stator and rotor		
Hypo-cycloids	2:1	3:2	4:3
Epi-cycloids	2:1	3:2	4:3
Hypo- & epi-cycloids	2:1	3:2	4:3

The general design of cylindrical Moineau pumps



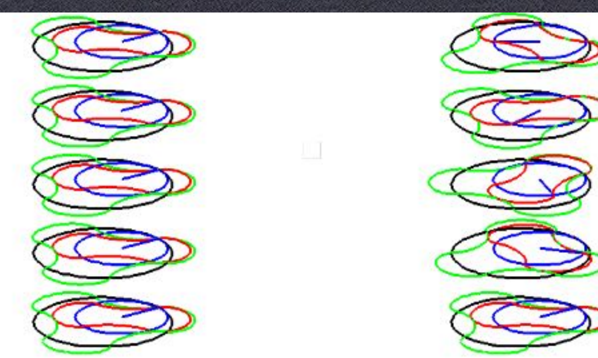
By looking at a horizontal section the design of a cylindrical Moineau pump is reduced to the design of two closed planar curves that are moved relative to each other by the motion generated by letting a circle of radius n-1 roll inside a circle of radius n. If the rotor is given then the stator can be determined as the envelope given by the motion of the rotor. In fact, the stator can be determined by the motion of a single convex arc of the rotor and the concave parts of the rotor can be found as envelope of the stator during the opposite motion. The whole proces is described here.

The determination of the envelope is a non-linear problem and can normally only be done numerically. But by using the support function to represent planar curves, see [2], the equations can be solved analytically and it is possible to find new designs in closed form, see [1,3].

Conical Moineau pumps

In the photo to the right a model of a concial Moineau pump is shown (a 2:1 hypo-cycloid construction). The cylindrical motion is replaced by a conical motion. That is, the motion is generated by letting two circular cones roll on each other.

We now intersect the construction with spheres centered

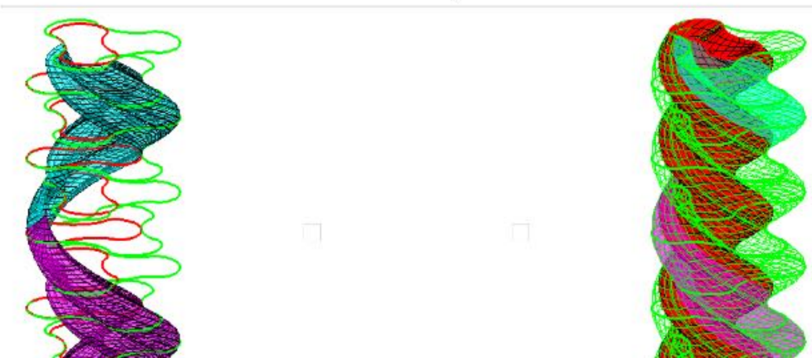


The construction above is lifted to horizontal planes z = constant.

The blue circle is rolled a distance proportional to the height z. Observe that the blue circles no longer are above each other.

By rotating the picture in each horizontal plane the blue circles can be positioned over each other such as to form a blue cylinder inside a black cylinder.

The motion generated by letting the blue cylinder roll inside the black cylinder is in each horzontal plane the same as before.



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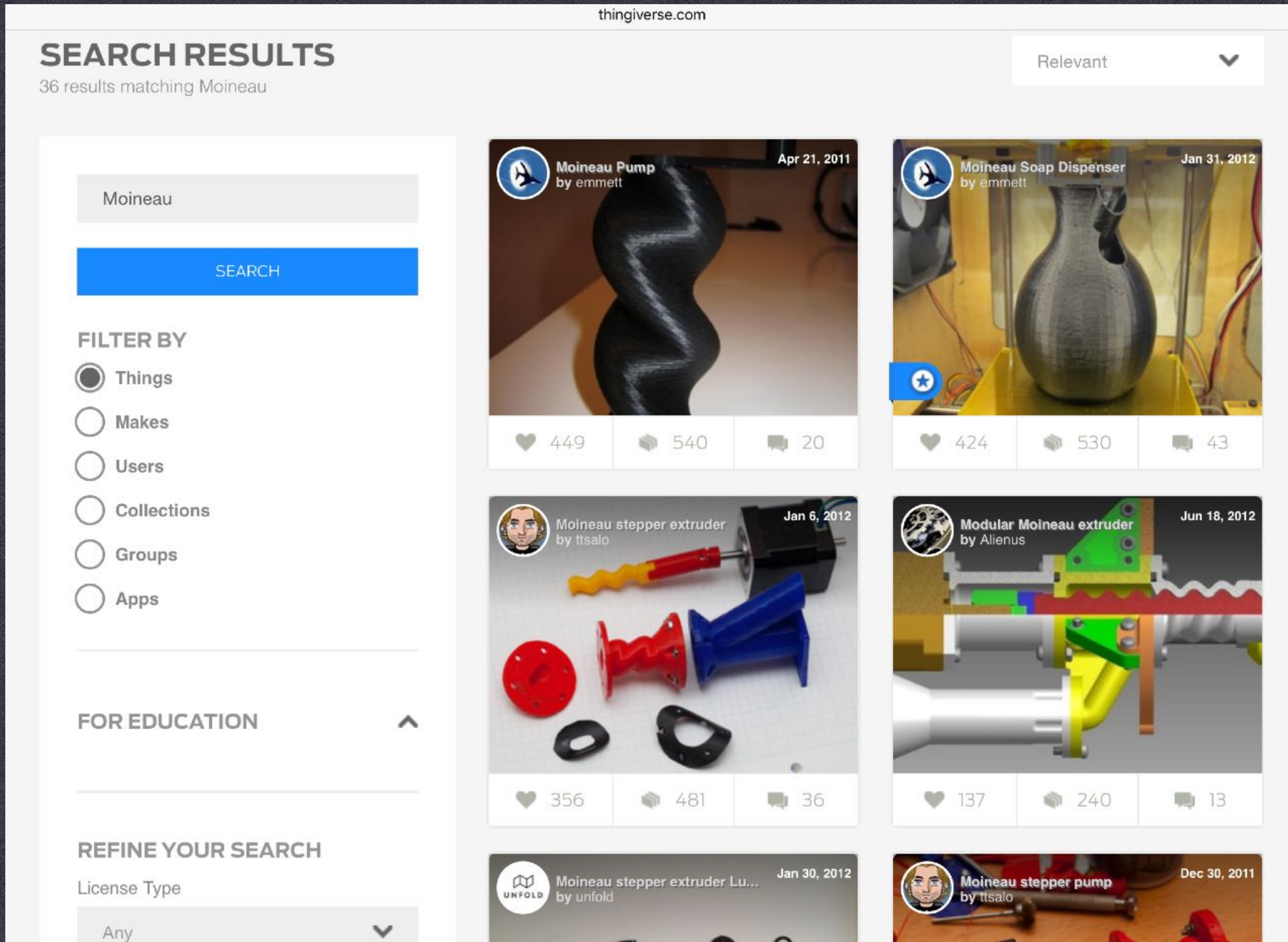
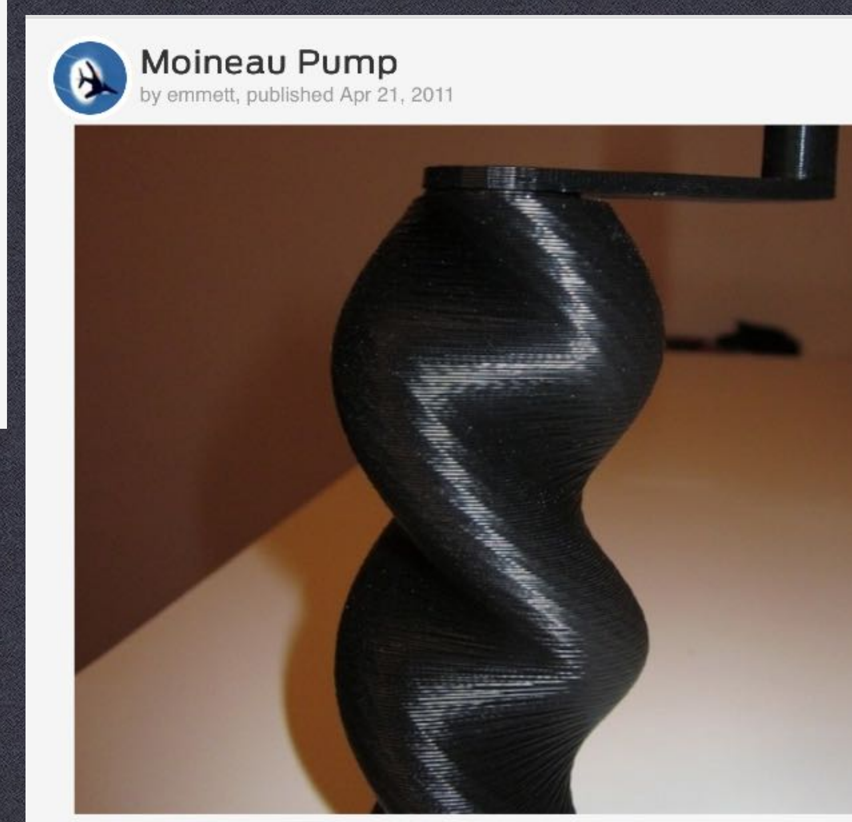




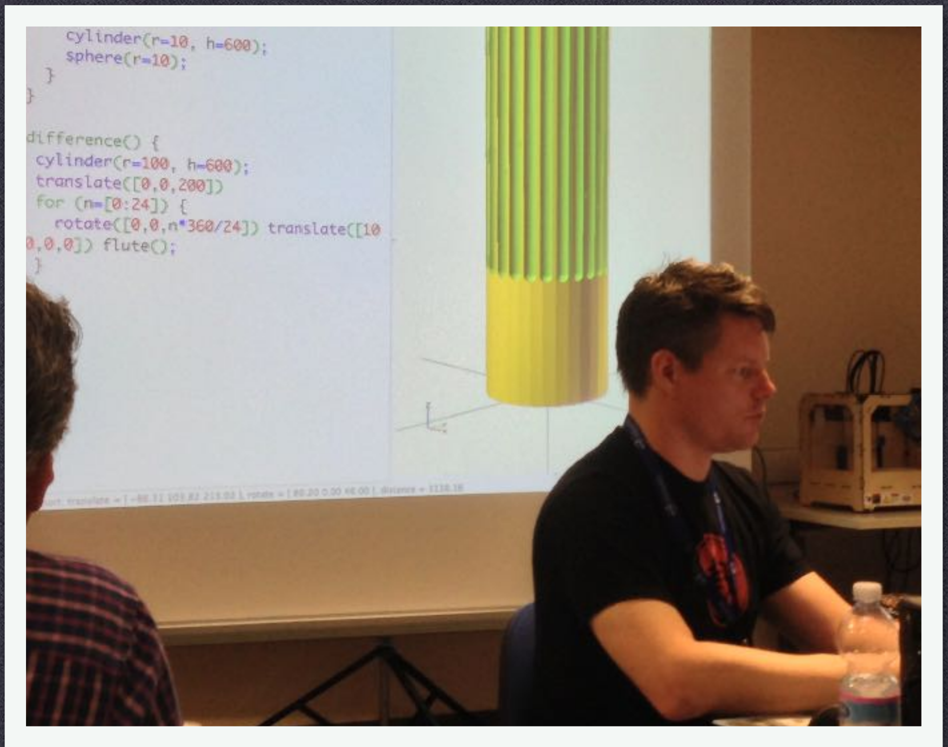
THINGIVERSE.COM

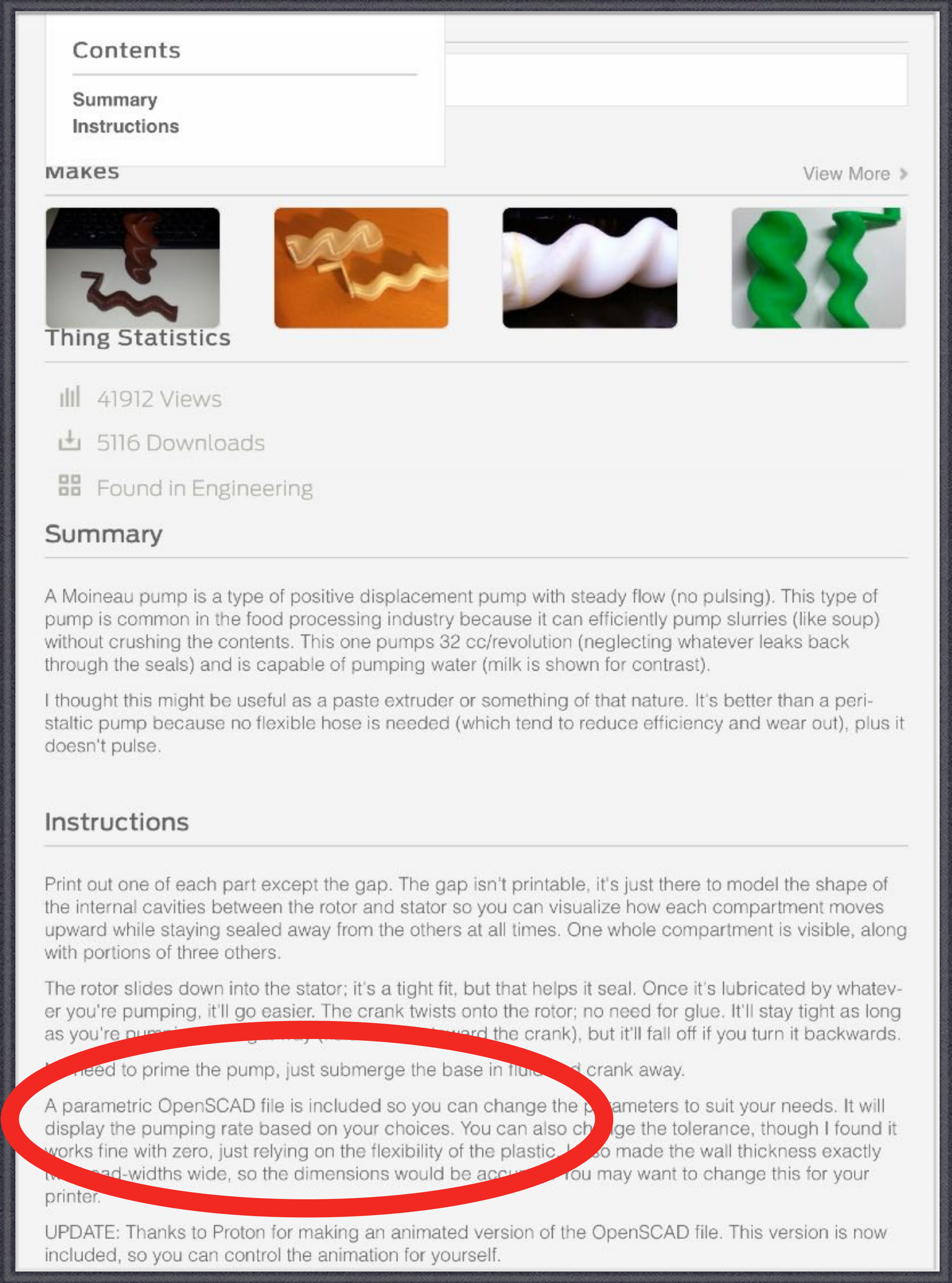
SEARCH FOR "MOINEAU" — WORKS BY TOMI SALO AND EMMETT LALISH

OPENSCAD
BY MARIUS KINTEL

OPENSCAD.ORG

OPENSOURCE (AND EASY!) LANGUAGE FOR 3D MODELING





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Summary

A Moineau pump is a type of positive displacement pump with steady flow (no pulsing). This type of pump is common in the food processing industry because it can efficiently pump slurries (like soup) without crushing the contents. This one pumps 32 cc/revolution (neglecting whatever leaks back through the seals) and is capable of pumping water (milk is shown for contrast).

I thought this might be useful as a paste extruder or something of that nature. It's better than a peri-staltic pump because no flexible hose is needed (which tend to reduce efficiency and wear out), plus it doesn't pulse.

Instructions

Print out one of each part except the gap. The gap isn't printable, it's just there to model the shape of the internal cavities between the rotor and stator so you can visualize how each compartment moves upward while staying sealed away from the others at all times. One whole compartment is visible, along with portions of three others.

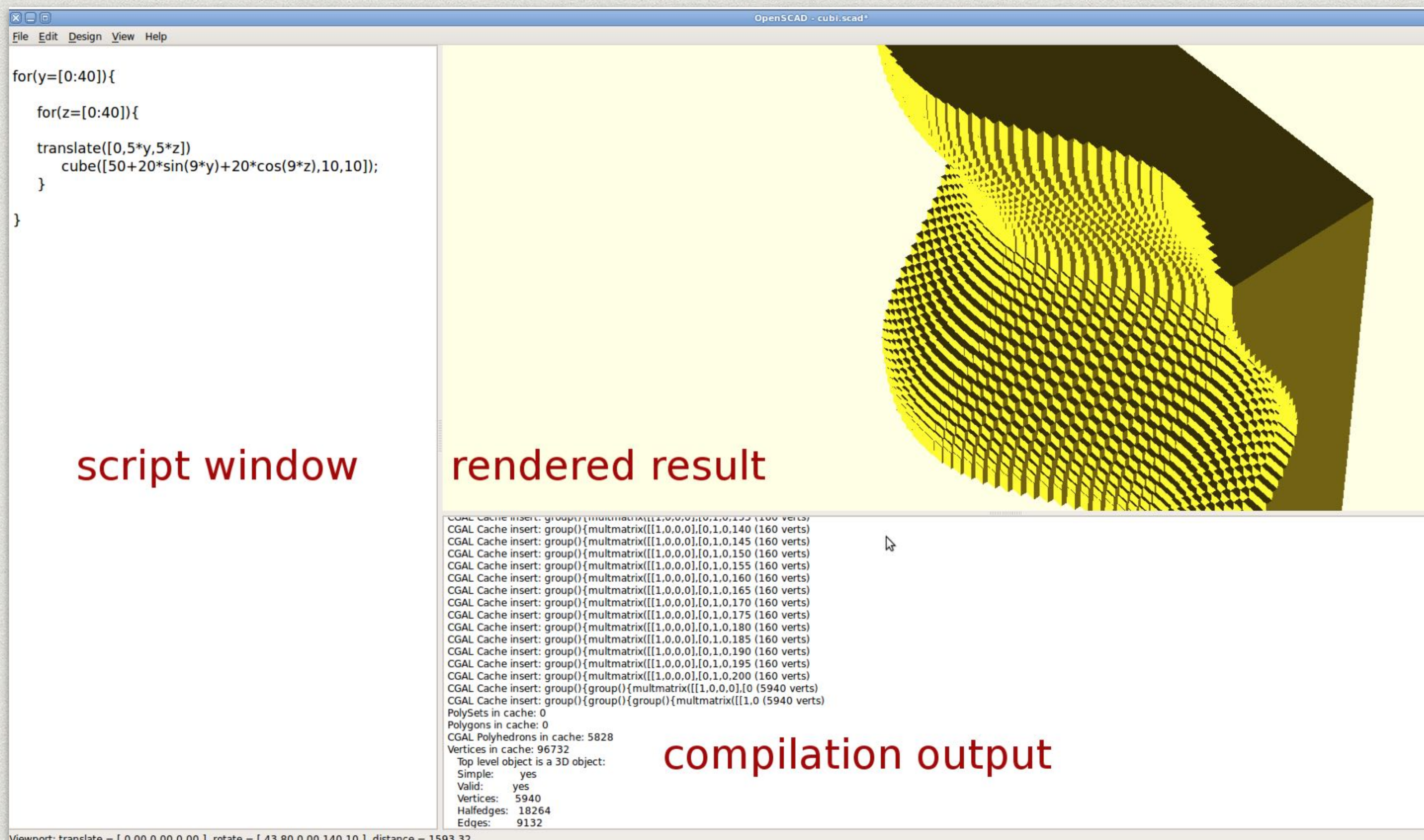
The rotor slides down into the stator; it's a tight fit, but that helps it seal. Once it's lubricated by whatev-er you're pumping, it'll go easier. The crank twists onto the rotor; no need for glue. It'll stay tight as long as you're pum... the crank), but it'll fall off if you turn it backwards.

...eed to prime the pump, just submerge the base in flu... crank away.

A parametric OpenSCAD file is included so you can change the p...ameters to suit your needs. It will display the pumping rate based on your choices. You can also ch...ge the tolerance, though I found it works fine with zero, just relying on the flexibility of the plastic. I...so made the wall thickness exactly ...ead-widths wide, so the dimensions would be accu... You may want to change this for your printer.

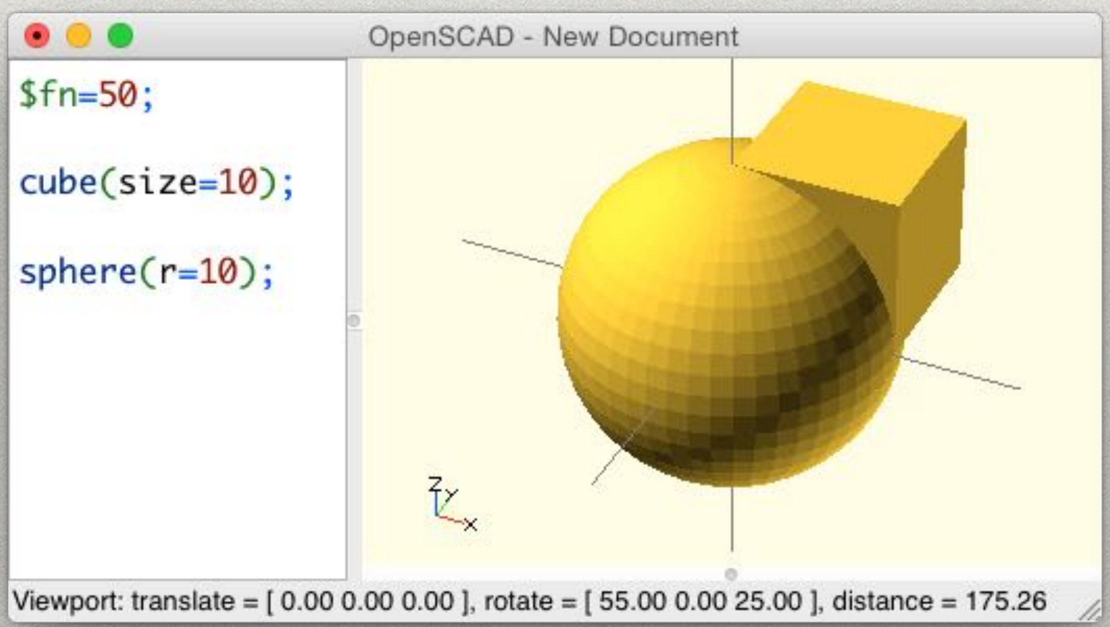
UPDATE: Thanks to Proton for making an animated version of the OpenSCAD file. This version is now included, so you can control the animation for yourself.

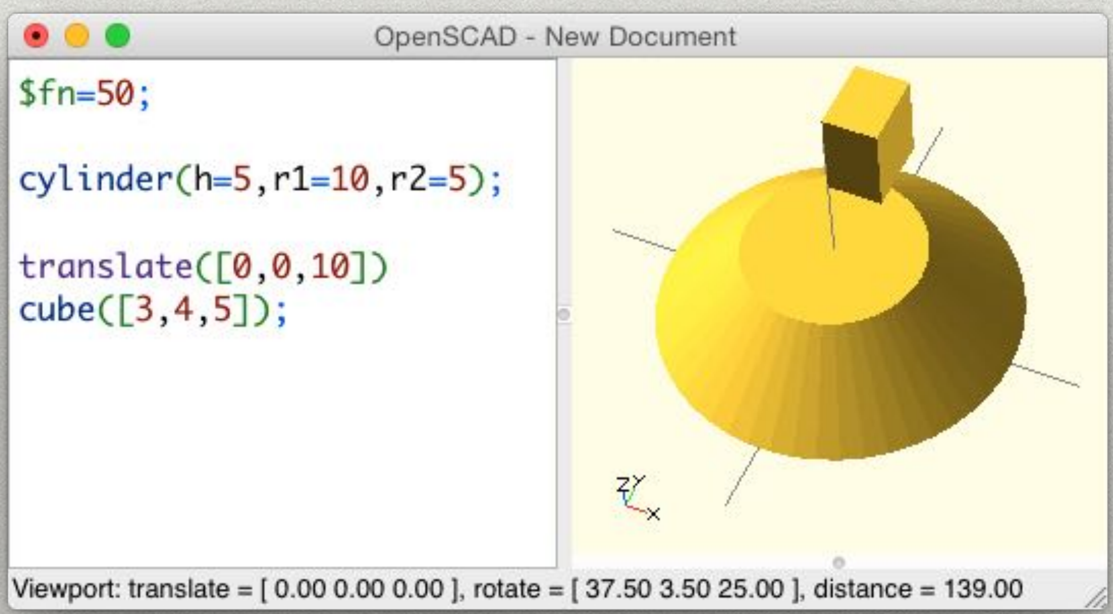
OpenSCAD interface



3D primitives

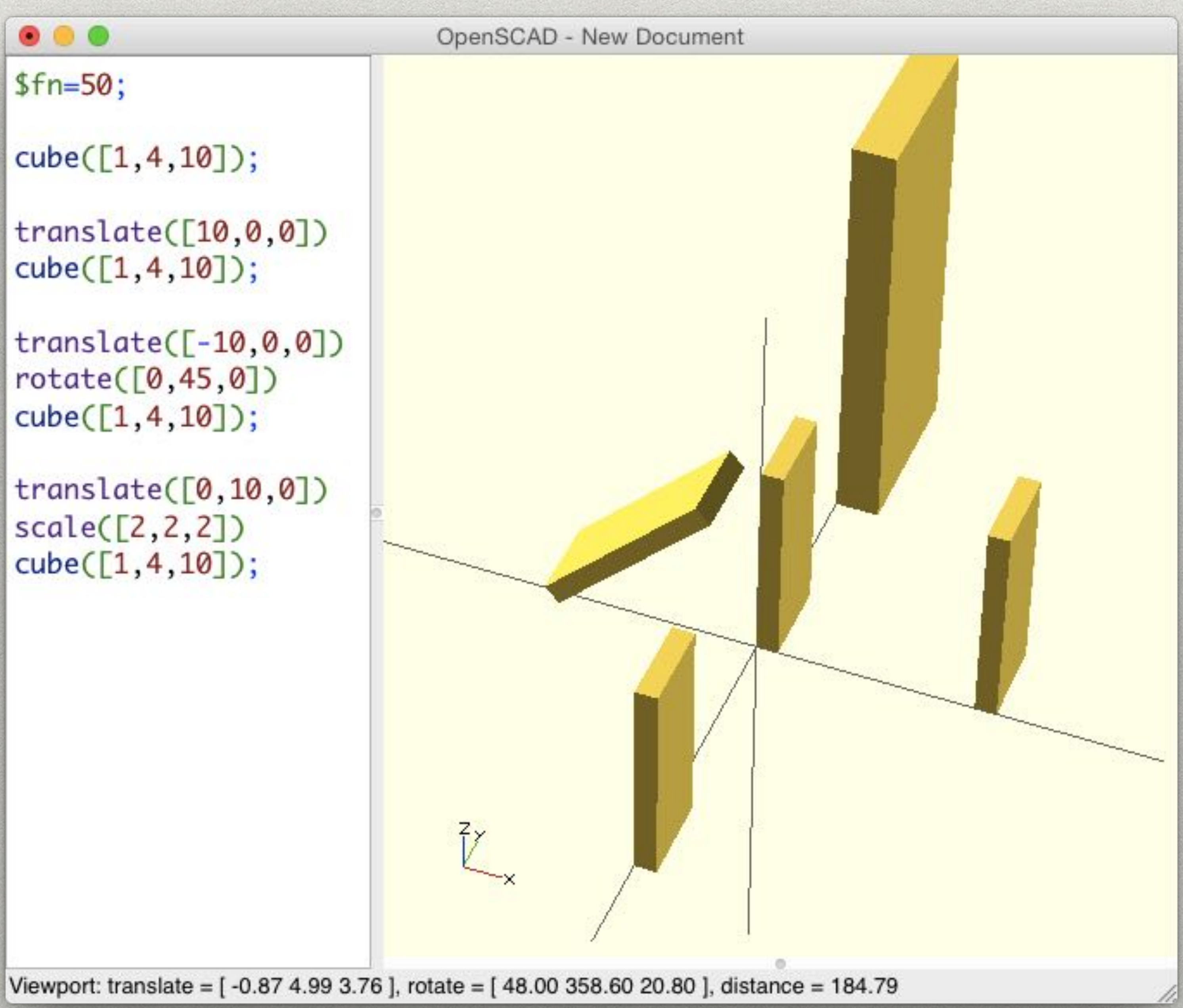
- **cube** (*size=10*) ;
- **sphere** (*radius=10*) ;
- **cylinder** (*h,r1, r2*) ;
- cube ([*width, height, depth*]) ;
- polygon ([points]) ;





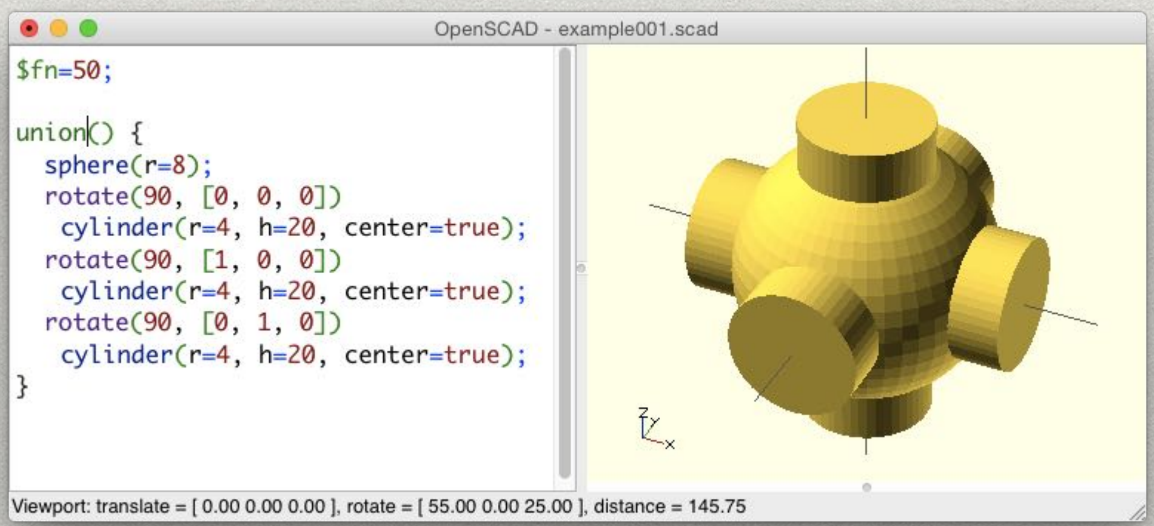
Transformations

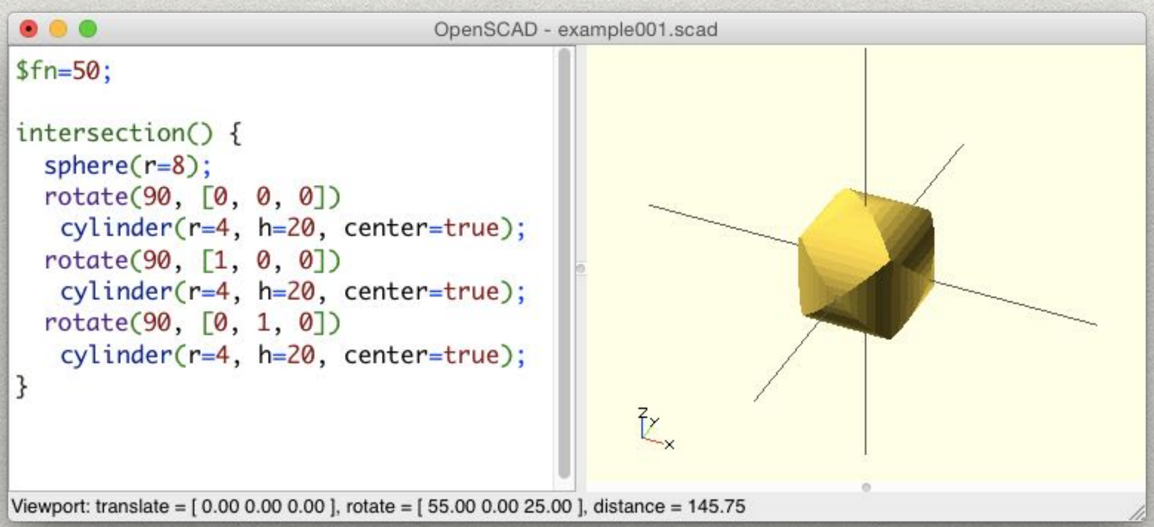
- translate ([*x*,*y*,*z*])
  primitives ;
- rotate ([*x*,*y*,*z*])
  primitives ;
- scale ([*x*,*y*,*z*])
  primitives ;
- mirror ([*x*,*y*,*z*])
  primitives ;

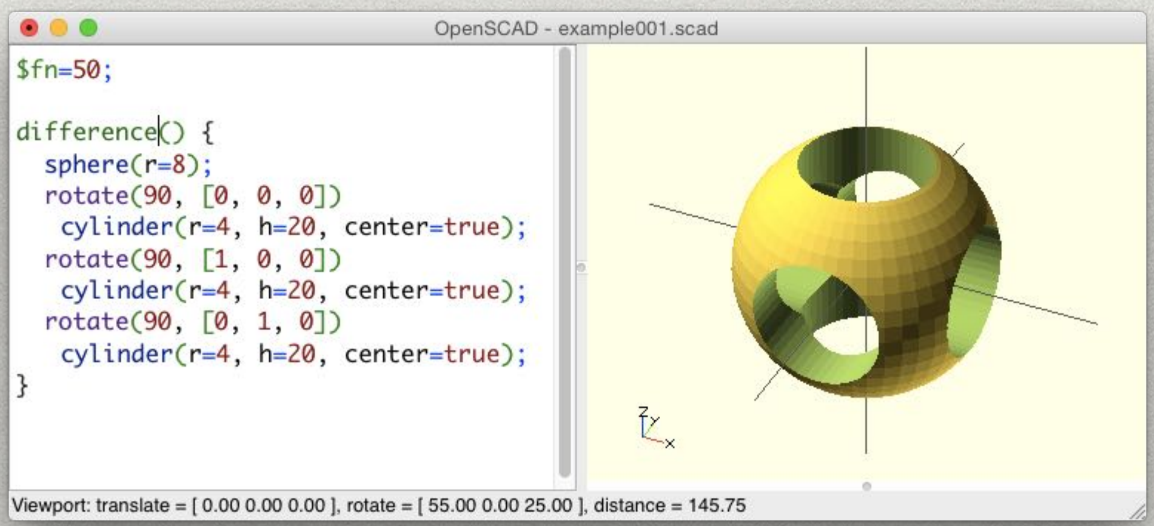


Boolean operations

- **union ()**
- **difference ()**
- **intersection ()**

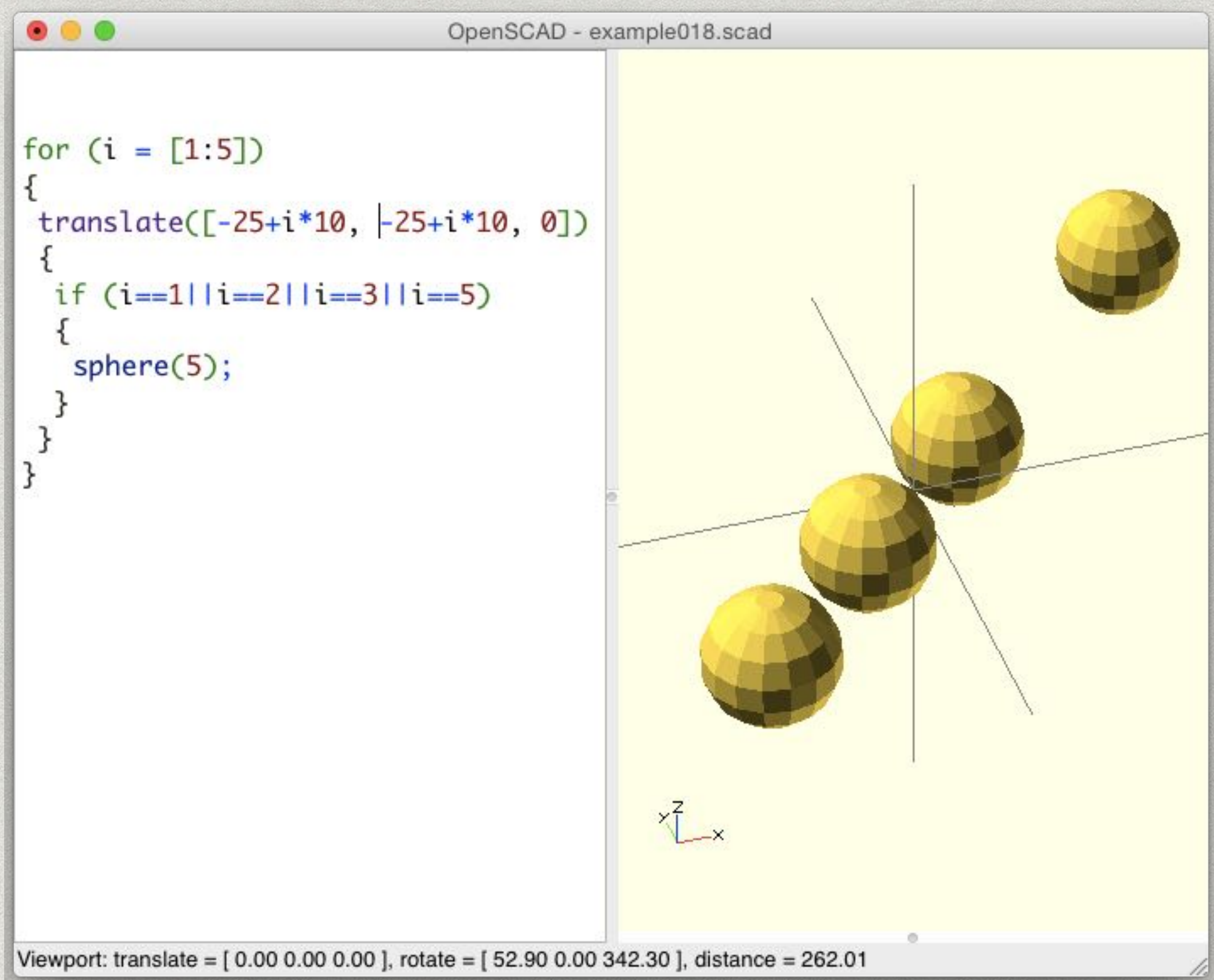






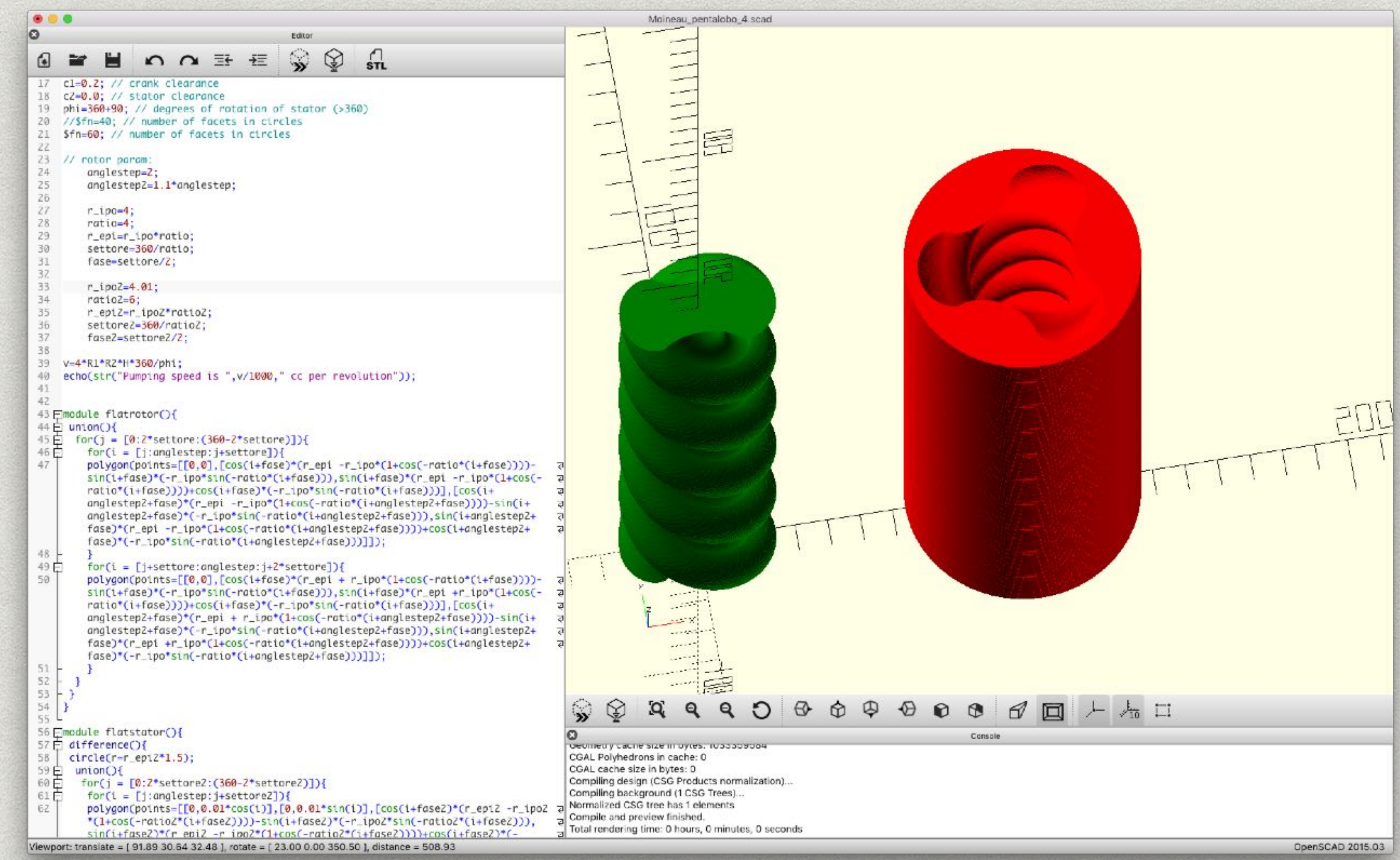
Loops & conditions

- **for** (i = [start:end])
  { … }
- **if** (condition)
  { … }
- … other usual stuff



Others

- many mathematical functions are available: power, root, trigonometrical, log, exponential, etc…
- functions, modules, include
- 2D primitives
- extrusion
- export as STL



List of all commands

OpenSCAD CheatSheet

Syntax
```
var = value;
module name(…) { … }
name();
function name(…) = …
name();
include <….scad>
use <….scad>
```

2D
```
circle(radius)
square(size,center)
square([width,height],center)
polygon([points])
polygon([points],[paths])
```

3D
```
sphere(radius)
cube(size)
cube([width,height,depth])
cylinder(h,r,center)
cylinder(h,r1,r2,center)
polyhedron(points, triangles, convexity)
```

Examples
```
cylinder(10,5,5);
cylinder(h=10,r=5);
```

Transformations
```
translate([x,y,z])
rotate([x,y,z])
scale([x,y,z])
mirror([x,y,z])
multmatrix(m)
color("colorname")
color([r, g, b, a])
hull()
minkowski()
```

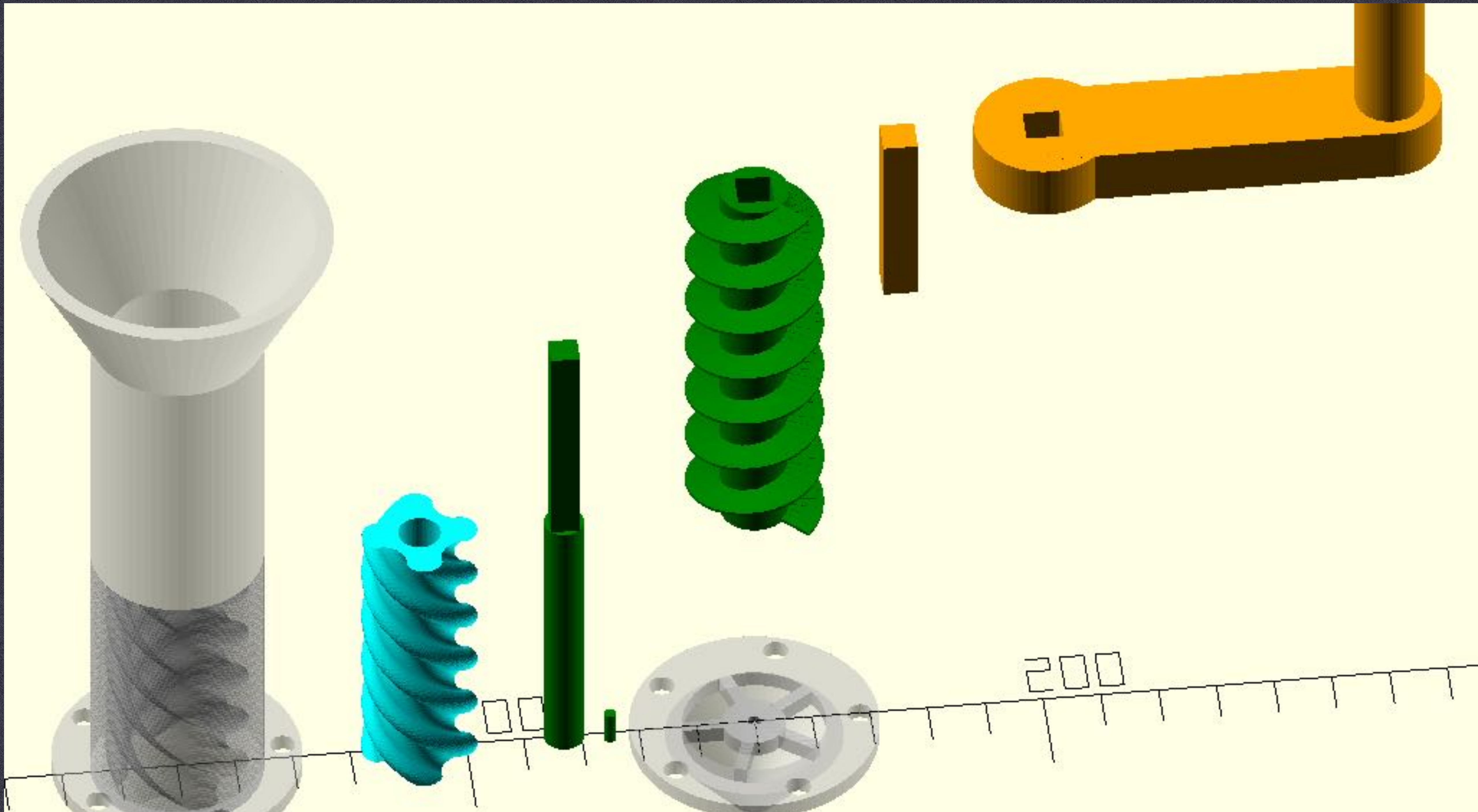
Boolean operations
```
union()
difference()
intersection()
```

Modifier Characters
```
*   disable
!   show only
#   highlight
%   transparent
```

Mathematical
```
abs
sign
acos
asin
atan
atan2
sin
cos
floor
round
ceil
ln
len
log
lookup
min
max
pow
sqrt
exp
rands
```

Other
```
echo(…)
str(…)
for (i = [start:end]) { … }
for (i = [start:step:end]) { … }
for (i = […,…,…]) { … }
intersection_for(i = [start:end]) { … }
intersection_for(i = [start:step:end]) { … }
intersection_for(i = […,…,…]) { … }
if (…) { … }
assign (…) { … }
search(…)
import("….stl")
linear_extrude(height,center,convexity,twist,slices)
rotate_extrude(convexity)
surface(file = "….dat",center,convexity)
projection(cut)
render(convexity)
```

Special variables
```
$fa minimum angle
$fs minimum size
$fn number of fragments
$t  animation step
```



PROJECT

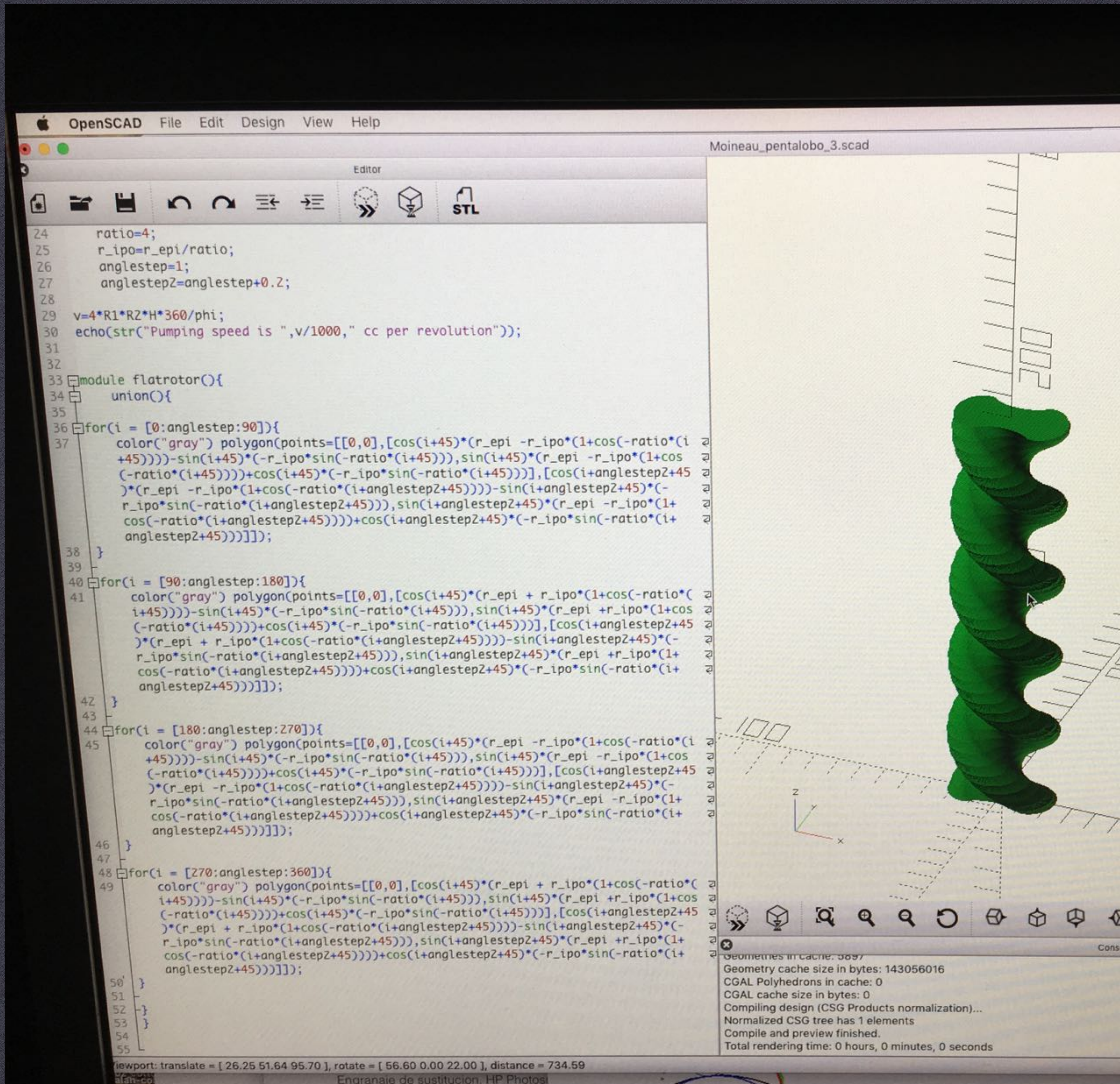
PELLEXTRUDER FIRST PROTOTYPE

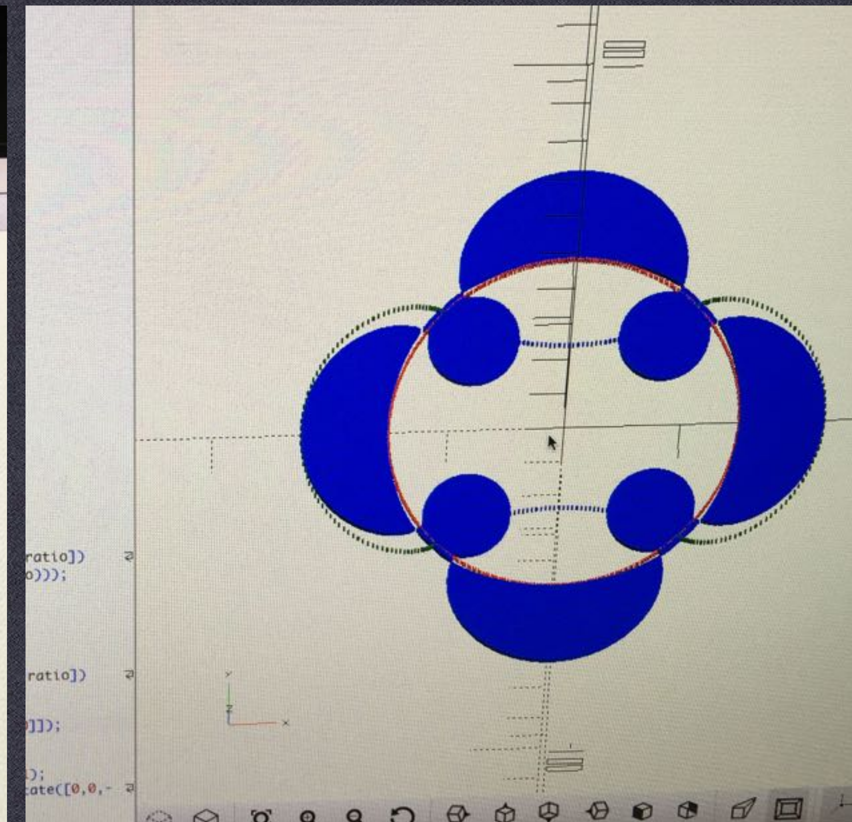
MODELED WITH OPENSCAD

DATE **SUMMER 2016**

CLIENT **CARLO FONDA (TNX TO EMMETT)**

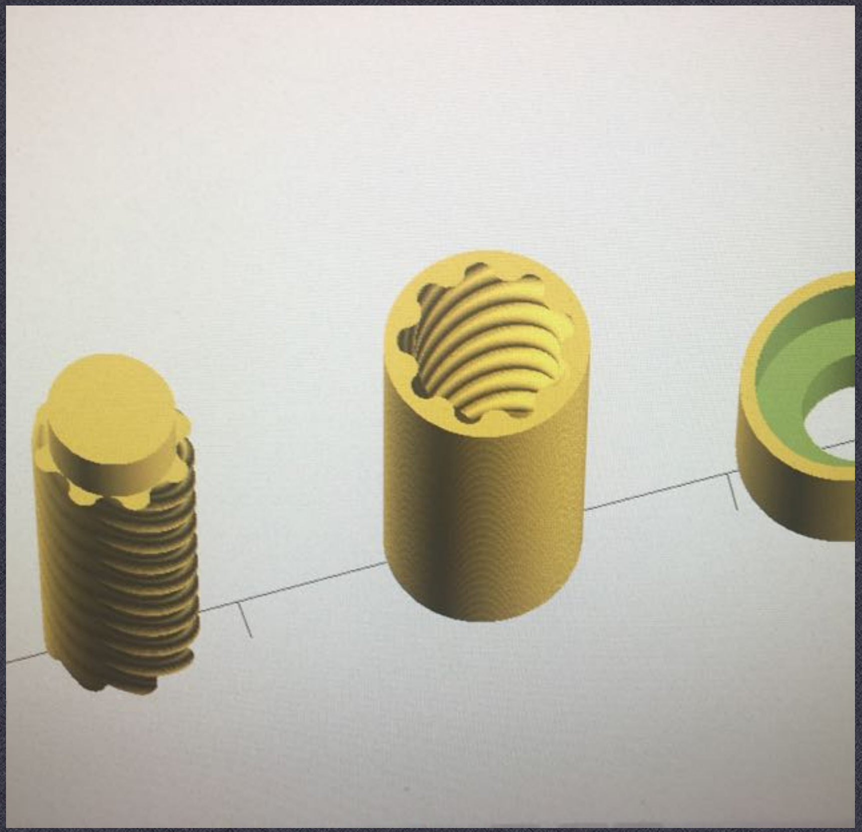
```
// prototype of a pellet extruder for 3D printer
// code (including mistakes) by Carlo Fonda (ICTP Scientific Fablab, Trieste, Italy)
// website: http://scifablab.ictp.it
// e-mail: cfonda@ictp.it
// version 0.1 - updated on Sun, July 24, 2016

// moineau code adapted from the original version made by emmet (21 april 2011)
// see: http://www.thingiverse.com/thing:7958 for the source
// multi-lobe implementation with the help of these very useful webpages:
// http://siags.siam.org/siaggd/problems/gravesen/Hypo2_1.html
// http://siags.siam.org/siaggd/problems/gravesen/HypoEpi3_2.html
// with animation and explainations. For more mathematical details see:
//https://www.semanticscholar.org/paper/The-geometry-of-the-Moineau-pump-Gravesen/964728c2b4285c2f7e7a0f05b43060bf6f2c2434/pdf

// Auger screw code uses the Auger OpenSCAD Library by wtgibson (7 June 2013)
// CREDIT: "Parametric Printable Auger" by William Gibson
// see: http://www.thingiverse.com/thing:96462 for the source

// credits: the idea to combine co-axially the two type of screw is by Marco Baruzzo
// credits: the willingness to move forward with this project is by Enrique Canessa
// motivation: this project has been submitted to the Rome Makerfaire (Edition 2016)



// main parameters to set:

// moineau section:
H=180;    // height of the moineau rotor
R_r=30;   // radius of the mpoineau rotor (envelope)
lobes=4;  // number of lobes of the moineau rotor (valid values: 2 to 9)
shell=6;  // moineau stator thickness
flange=5;  // bottom/top flange thickness
tolerance=1;  // moineau rotor/stator gap

```





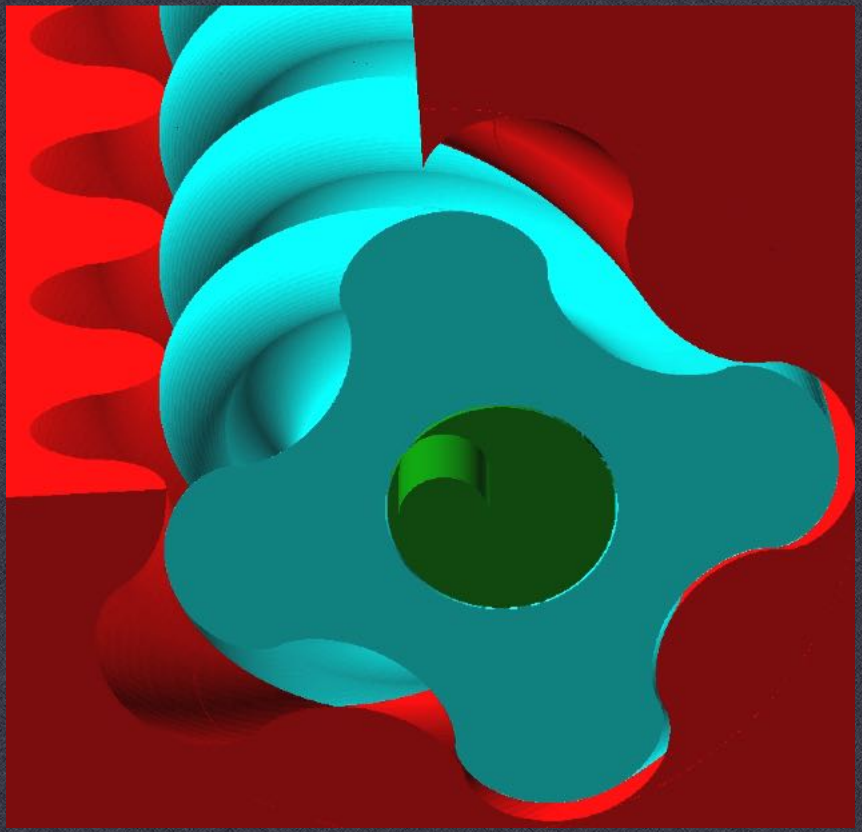

ONE OF MANY VERSIONS OF THE FIRST DESIGN

EXPERIMENTS WITH DIFFERENT NUMBER OF LOBES / DIMENSIONS / RATIOS / ETC...



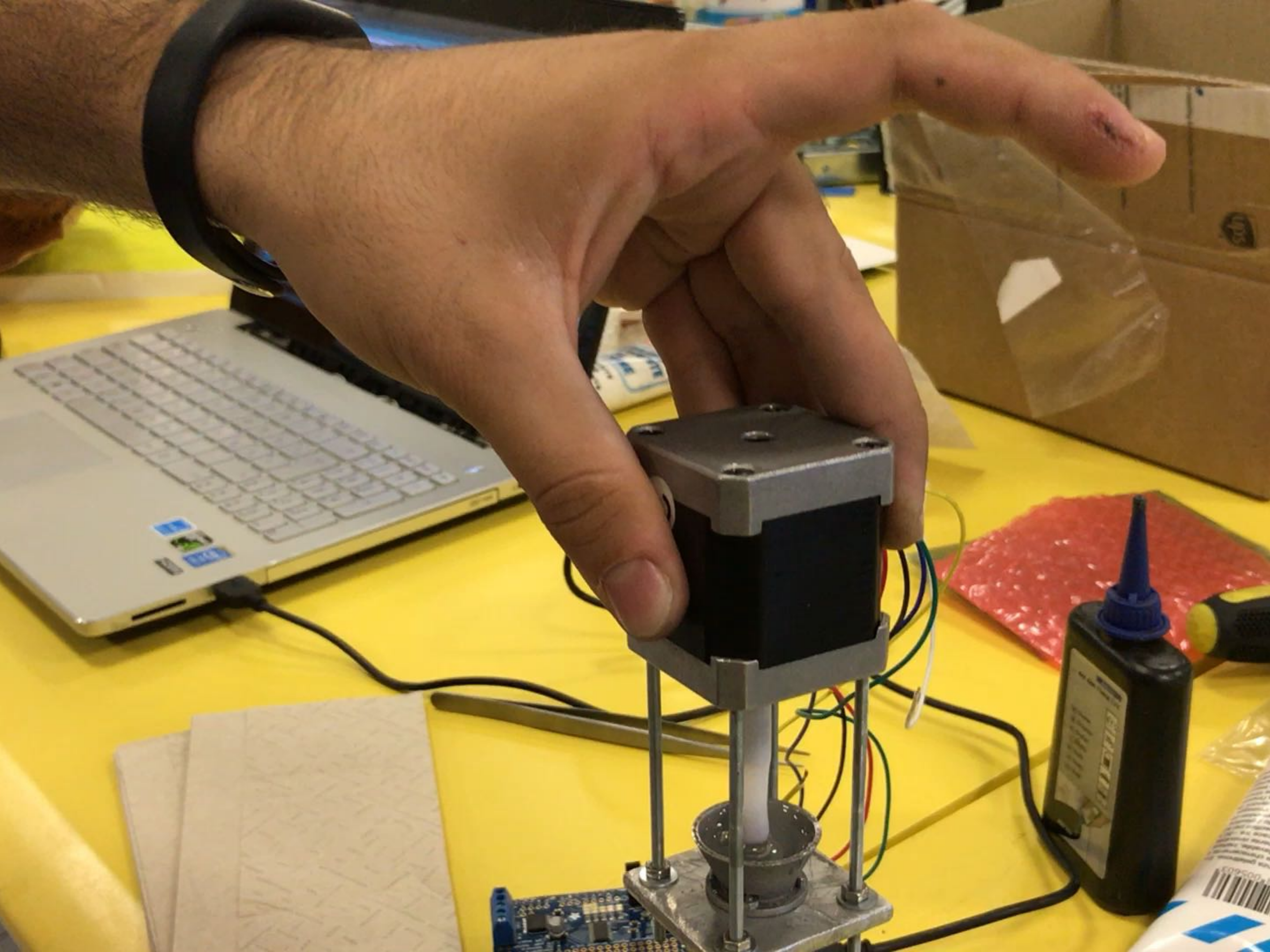
ONE OF MANY VERSIONS OF THE FIRST DESIGN

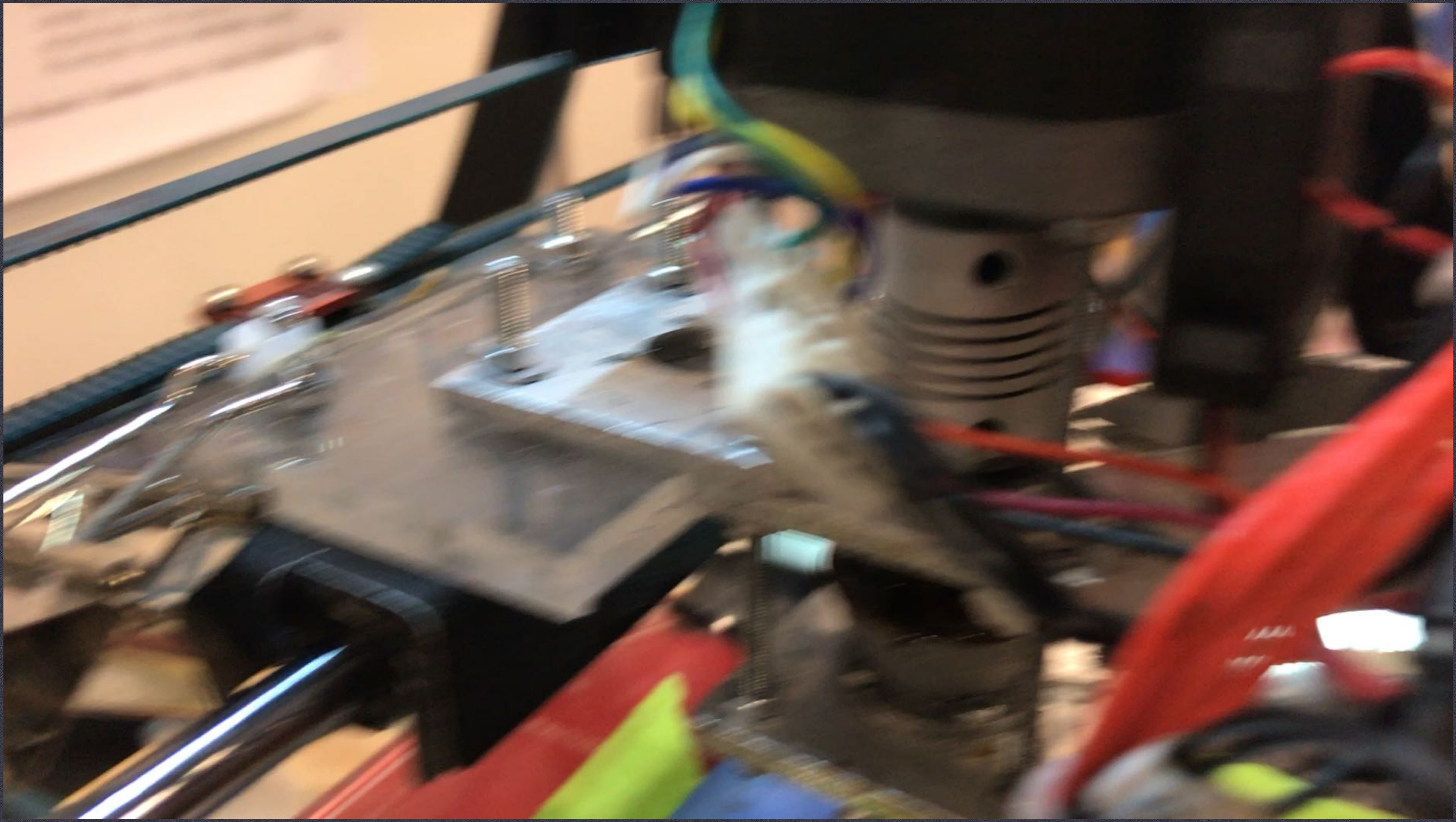
EXPERIMENTS WITH DIFFERENT NUMBER OF LOBES / DIMENSIONS / RATIOS / ETC...



FIRST WORKING PROTOTYPE 3D PRINTED IN ALUMINUM

READY (JUST IN TIME) FOR THE ROME MAKER FAIRE IN OCTOBER 2016...





PROJECT

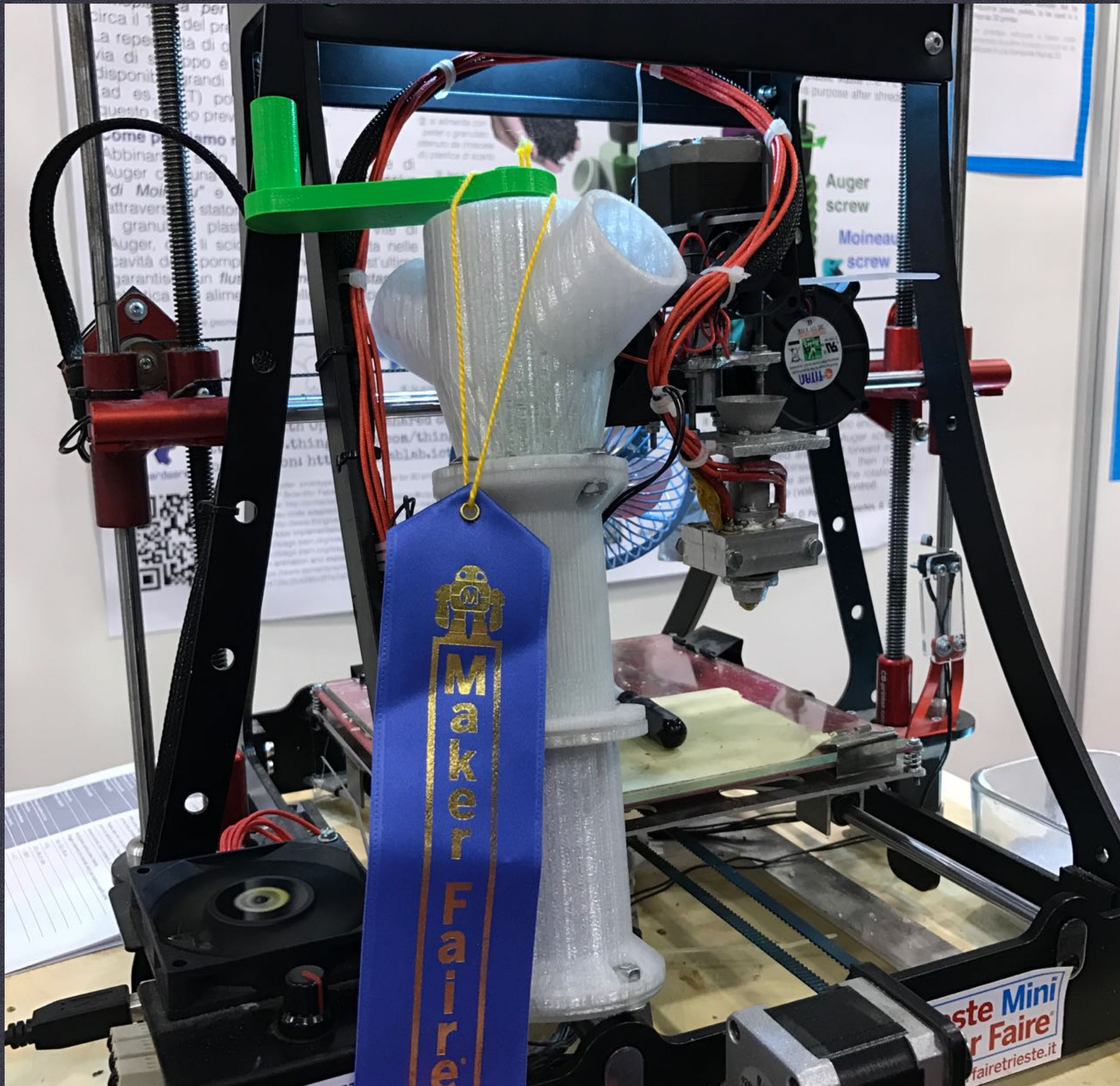
DEMO: 3D PRINTED CHOCOLATE

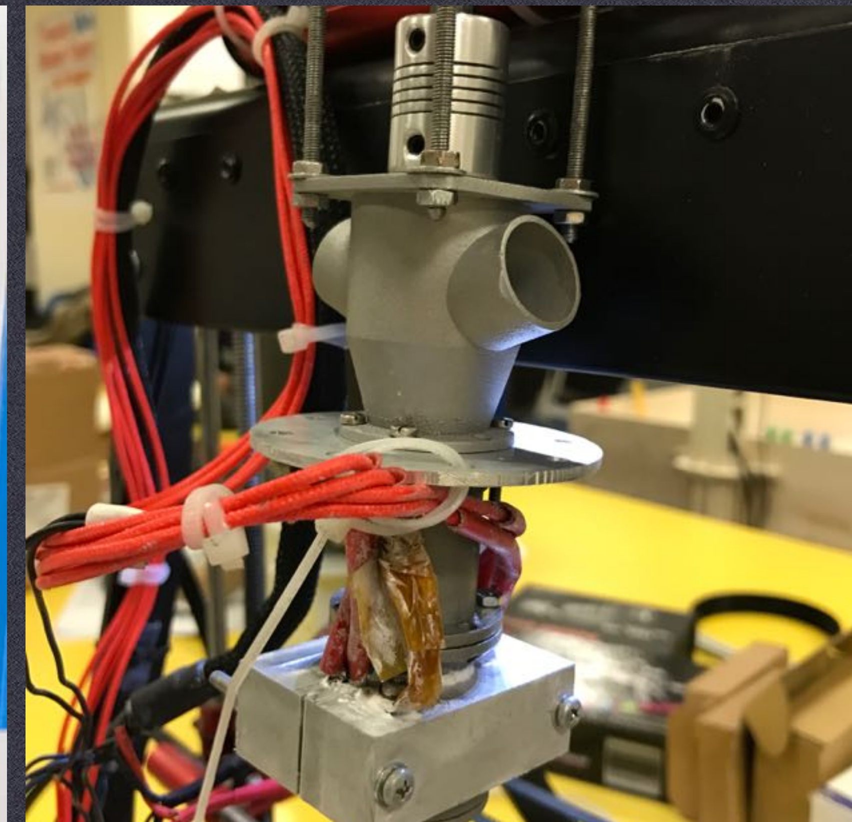
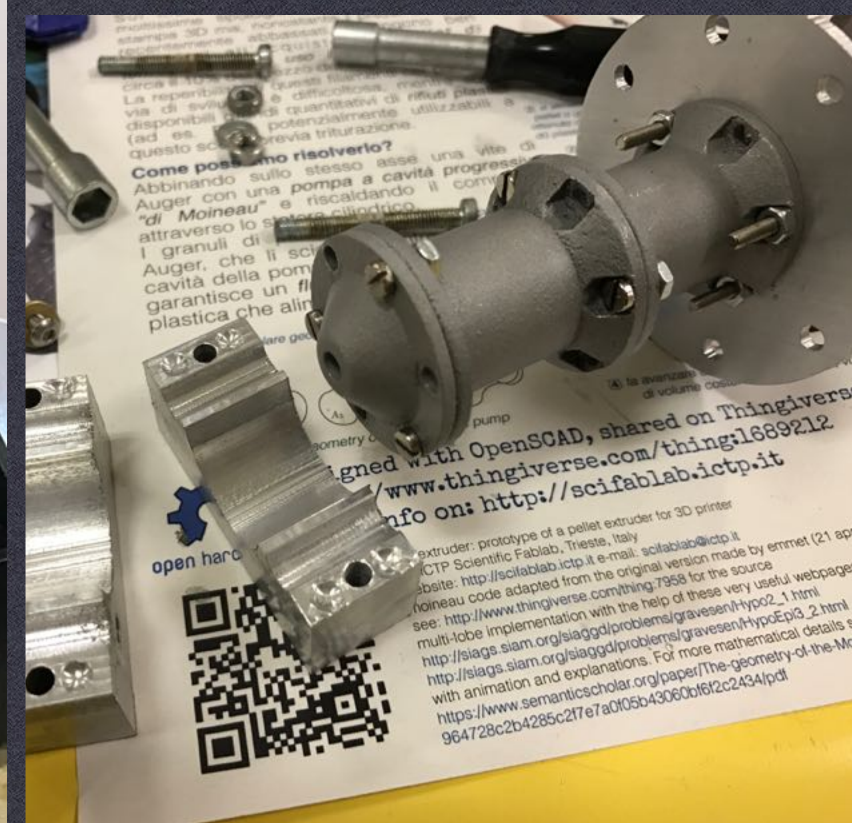
@ MAKERFAIRE ROME

DATE **OCTOBER 2016**

CLIENT **ICTP SCIFABLAB**

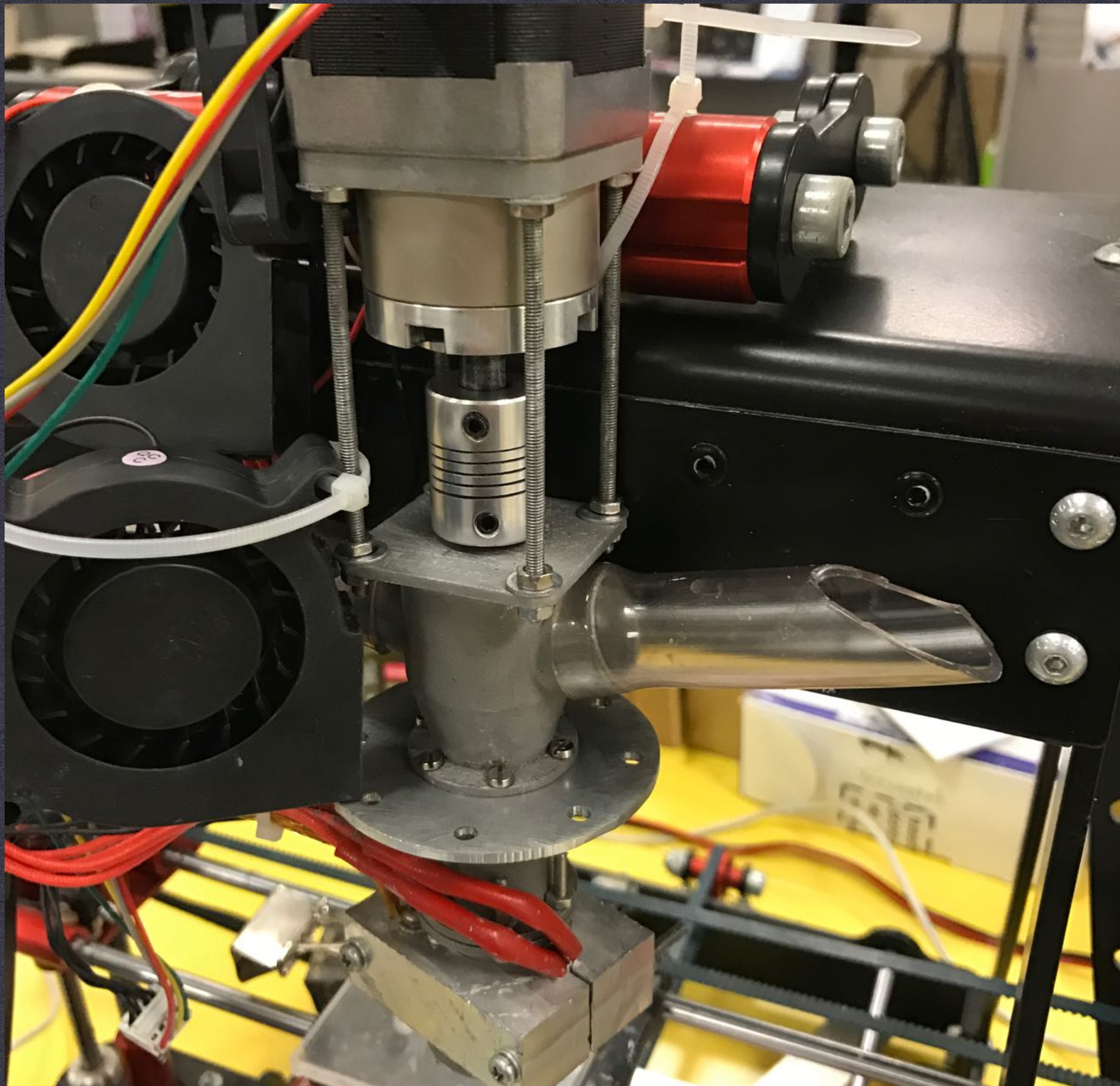

uder (pellets-fed extruder for 3D printing)
WE NEED YOUR BEAUTIFUL MIND. NOW!
Auger screw
Moineau screw
Maker Faire
PELLEXTRUDER
ICTP
International Centre for Theoretical Physics
Scientific FabLab
scifablab.ictp.it
STAFF
ANGEL
Trieste Mini Maker Faire
Ultimaker

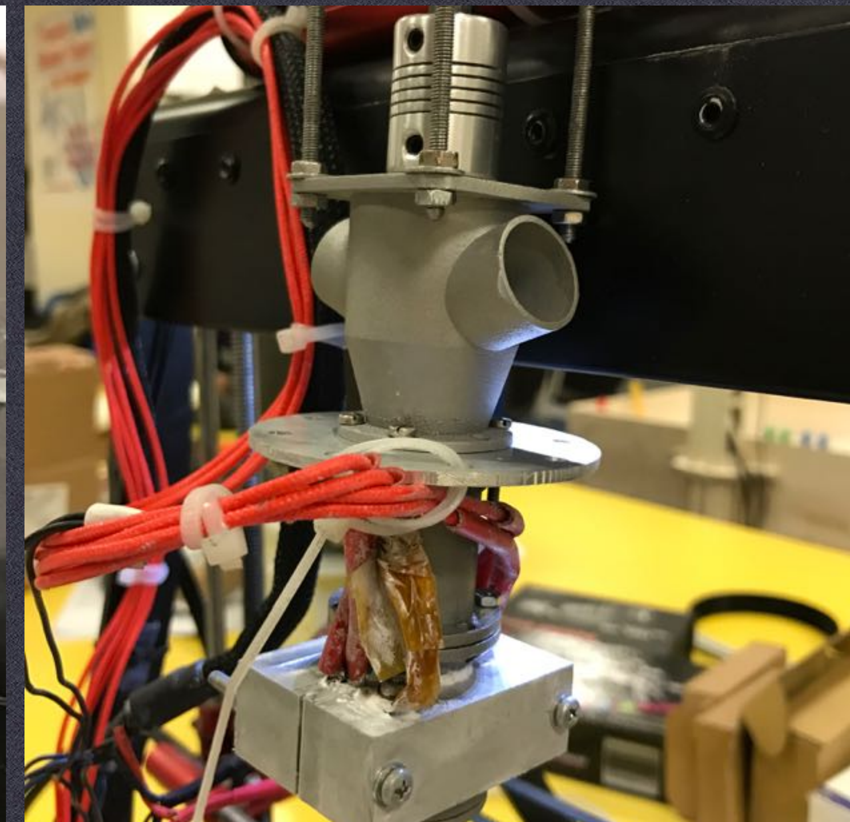


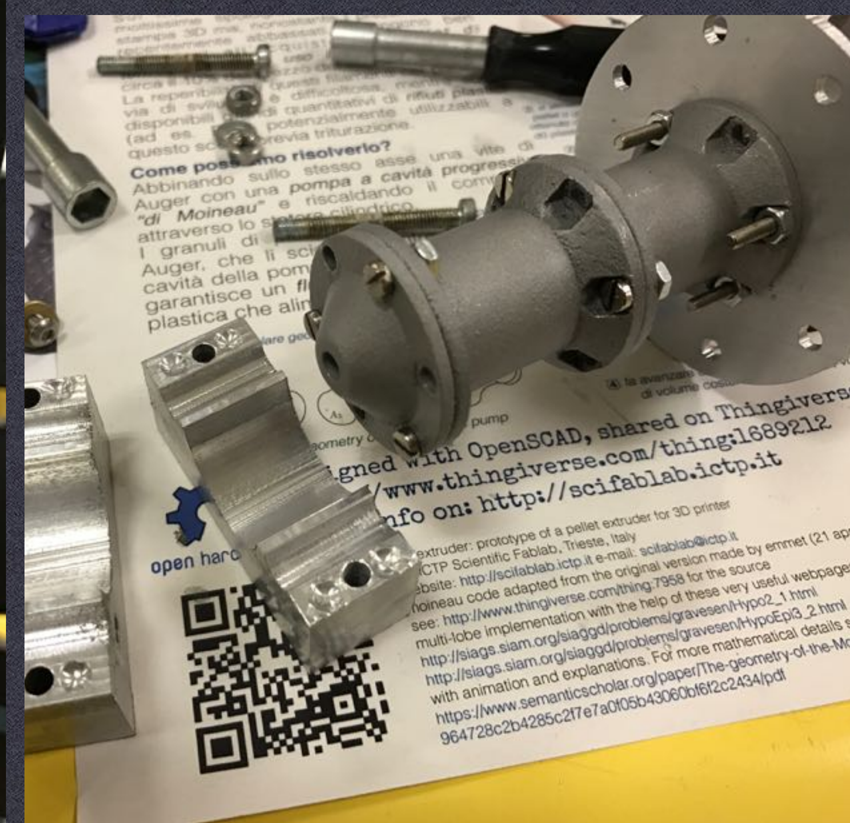



BADGE OF MERIT (BLUE RIBBON) @ MAKERFAIRE ROME 2016

GIVEN BY MATT STULTZ (DIGITAL FABRICATION EDITOR, MAKE MAGAZINE)







SECOND (IMPROVED) DESIGN AFTER ROME MAKERFAIRE

BETTER FUNNEL, LARGER SIZE FOR AUGER AND MOINEAU (MORE EXPENSIVE BUT EASIER TO WORK WITH...)

Pellextruder (pellets-fed extruder for 3D printing)

Bibliographic Reference: "Fonda, Carlo. (2016). Heated volumetric extrusion mechanism with co-axial Auger and Moineau pumps for 3D printing from plastic pellets. **Zenodo.10.5281/zenodo.59241"**

Qual è il problema?

Sul mercato sono ormai disponibili moltissime tipologie di filamento per la stampa 3D ma, nonostante i prezzi si siano recentemente abbassati, rimangono ben superiori all'acquisto dei ***pellet di termoplastica per uso industriale*** (~1€/kg, circa il 10% del prezzo del filamento).

La reperibilità di questi filamenti nei paesi in via di sviluppo è difficoltosa, mentre sono disponibili grandi quantitativi di ***rifiuti plastici*** (ad es. PET) potenzialmente utilizzabili a questo scopo previa triturazione.

Come possiamo risolverlo?

Abbinando sullo stesso asse una vite di Auger con una ***pompa a cavità progressiva "di Moineau"*** e riscaldando il complesso attraverso lo statore cilindrico.

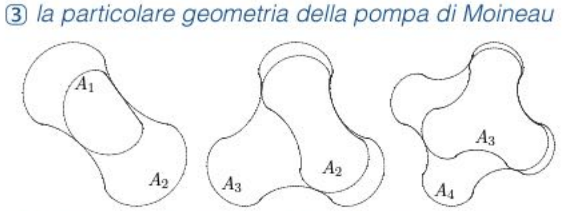
I granuli di plastica entrano nella vite di Auger, che li scioglie mentre li porta nelle cavità della pompa di Moineau. Quest'ultima garantisce un ***flusso volumetrico costante*** di plastica che alimenta l'ugello di stampa.

① uno stepper motor gira la vita di Auger, che a sua volta tramite un asse eccentrico aziona la vite di Moineau

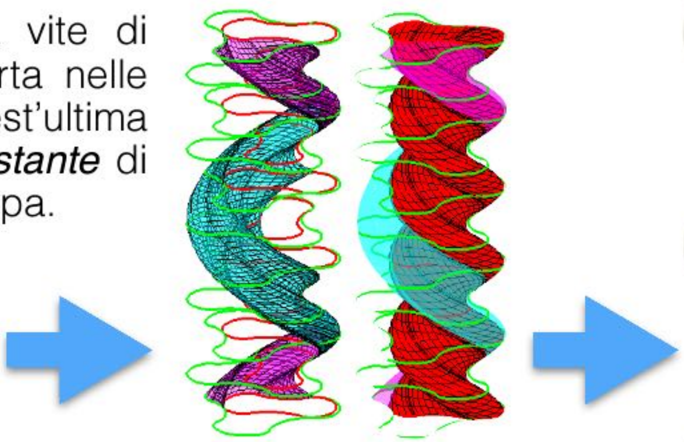
② si alimenta con pellet o granulato ottenuto da (miscele di) plastica di scarto

② fed by shredded recycled plastic (mixture) or pellets

③ la particolare geometria della pompa di Moineau



③ the special geometry of the Moineau pump



④ fa avanzare delle cavità di volume costante

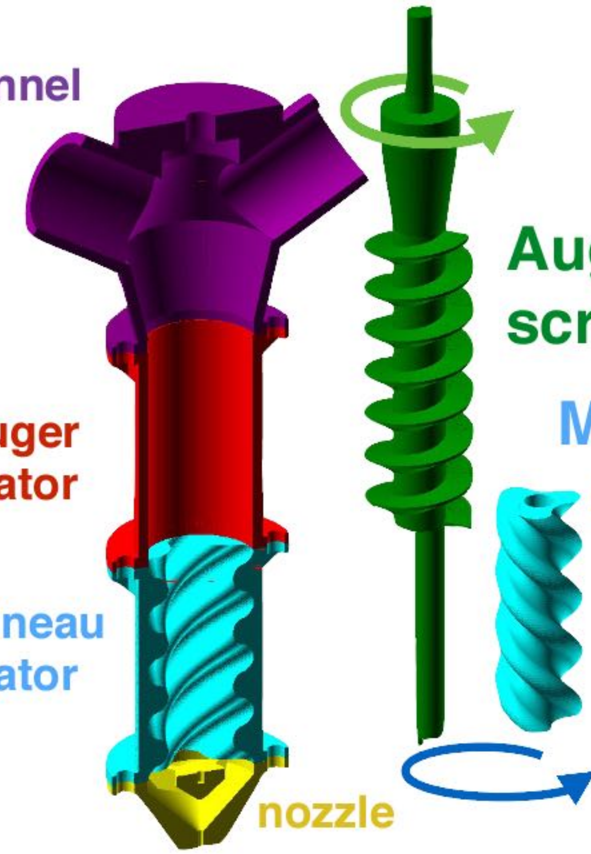
④ it moves forward constant-volume cavities

⑤ col risultato di un controllo molto preciso del volume di estruso

⑤ giving a fine control of the extruded volume

What is the issue?

It is now possible to buy a huge variety of plastic filaments for 3D printing, but even though they have become progressively cheaper, ***industrial plastic pellets*** cost a fraction (~1€/kg, roughly 10%). Their availability in developing countries is still difficult, while there is a huge amount of ***plastic waste*** (i.e. PET) that could be used for this purpose after shredding.



How can we solve it?

Coupling on the same axis an Auger screw with a ***"Moineau" progressive cavity pump*** and heating it all through the cylindric enclosure.

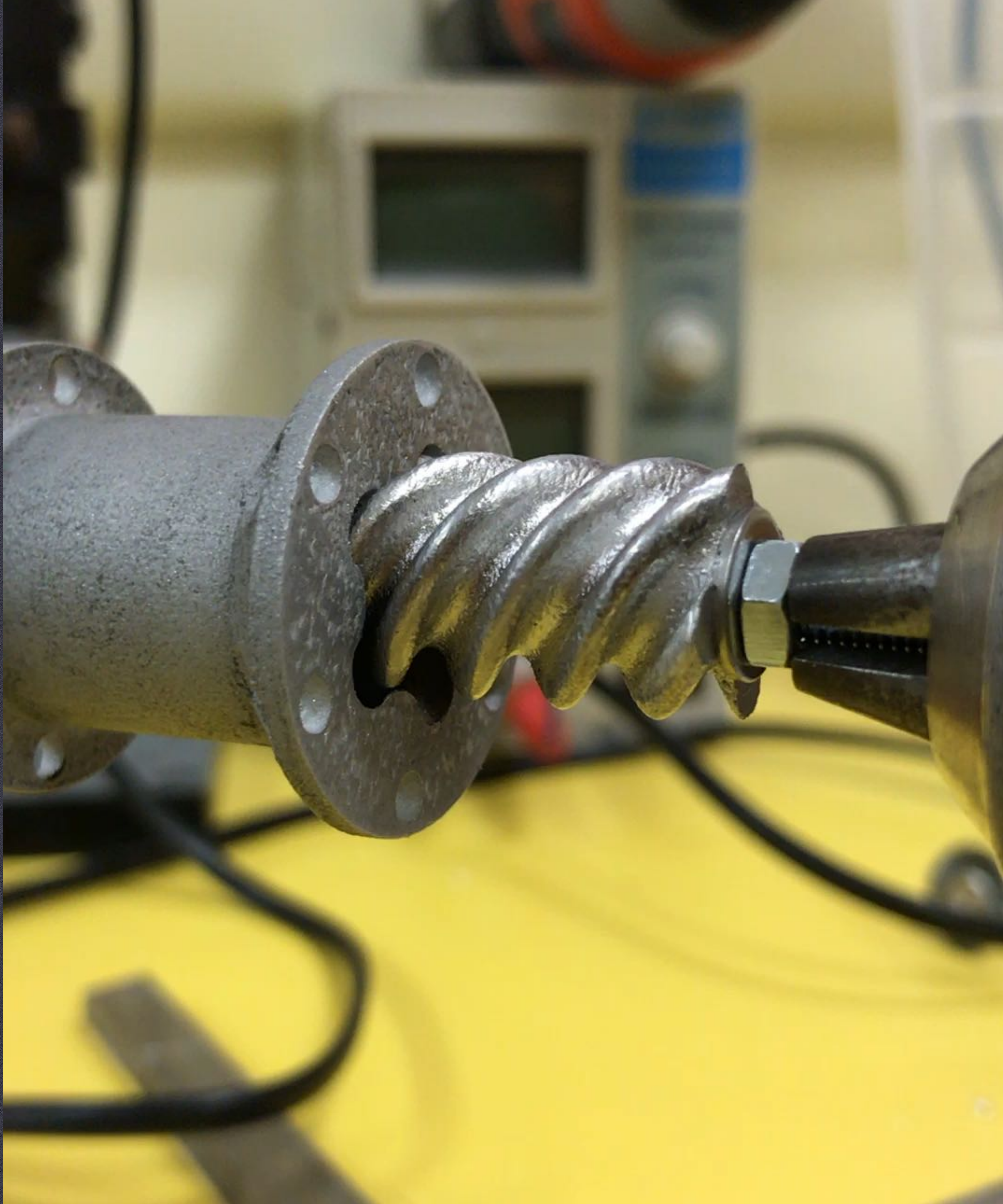
The plastic pellets enter the Auger screw and while being melted are moved forward into the cavities of the Moineau pump, then pushed proportionally to the amount of the rotation into the extrusion nozzle (*volumetric control*).

open hardware

Designed with OpenSCAD, shared on Thingiverse
http://www.thingiverse.com/thing:1689212
more info on: http://scifablab.ictp.it

Pellextruder: prototype of a pellet extruder for 3D printer
by ICTP Scientific Fablab, Trieste, Italy
website: http://scifablab.ictp.it e-mail: scifablab@ictp.it
moineau code adapted from the original version made by emmet (21 april 2011)
see: http://www.thingiverse.com/thing:7958 for the source
multi-lobe implementation with the help of these very useful webpages:
http://siags.siam.org/siaggd/problems/gravesen/Hypo2_1.html
http://siags.siam.org/siaggd/problems/gravesen/HypoEpi3_2.html
with animation and explanations. For more mathematical details see:
https://www.semanticscholar.org/paper/The-geometry-of-the-Moineau-pump-Gravesen/964728c2b4285c2f7e7a0f05b43060bf6f2c2434/pdf

Authors: M. Baruzzo, E. Canessa, G. Fior, C. Fonda, E. Ronchin, S. Sossi

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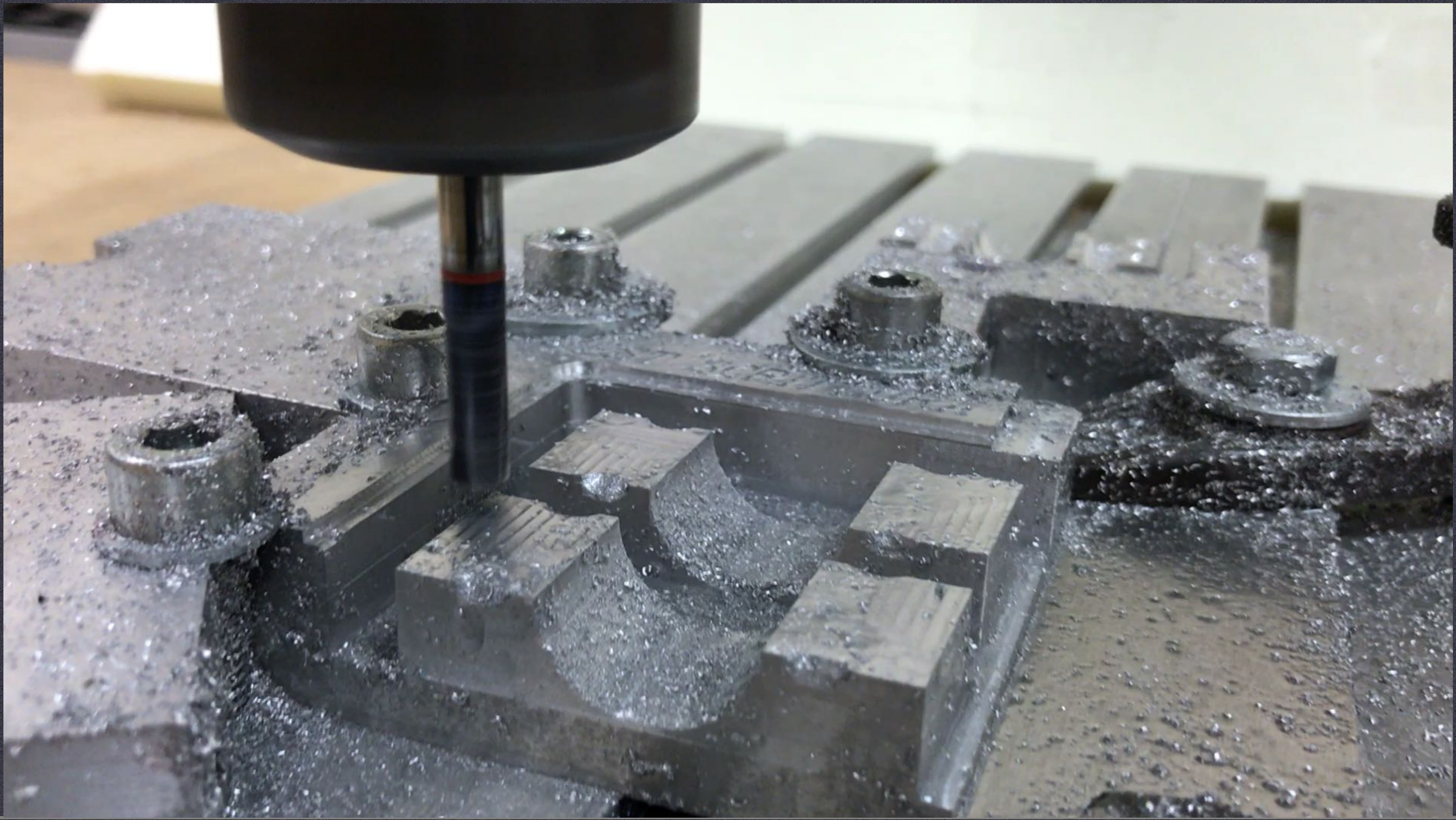


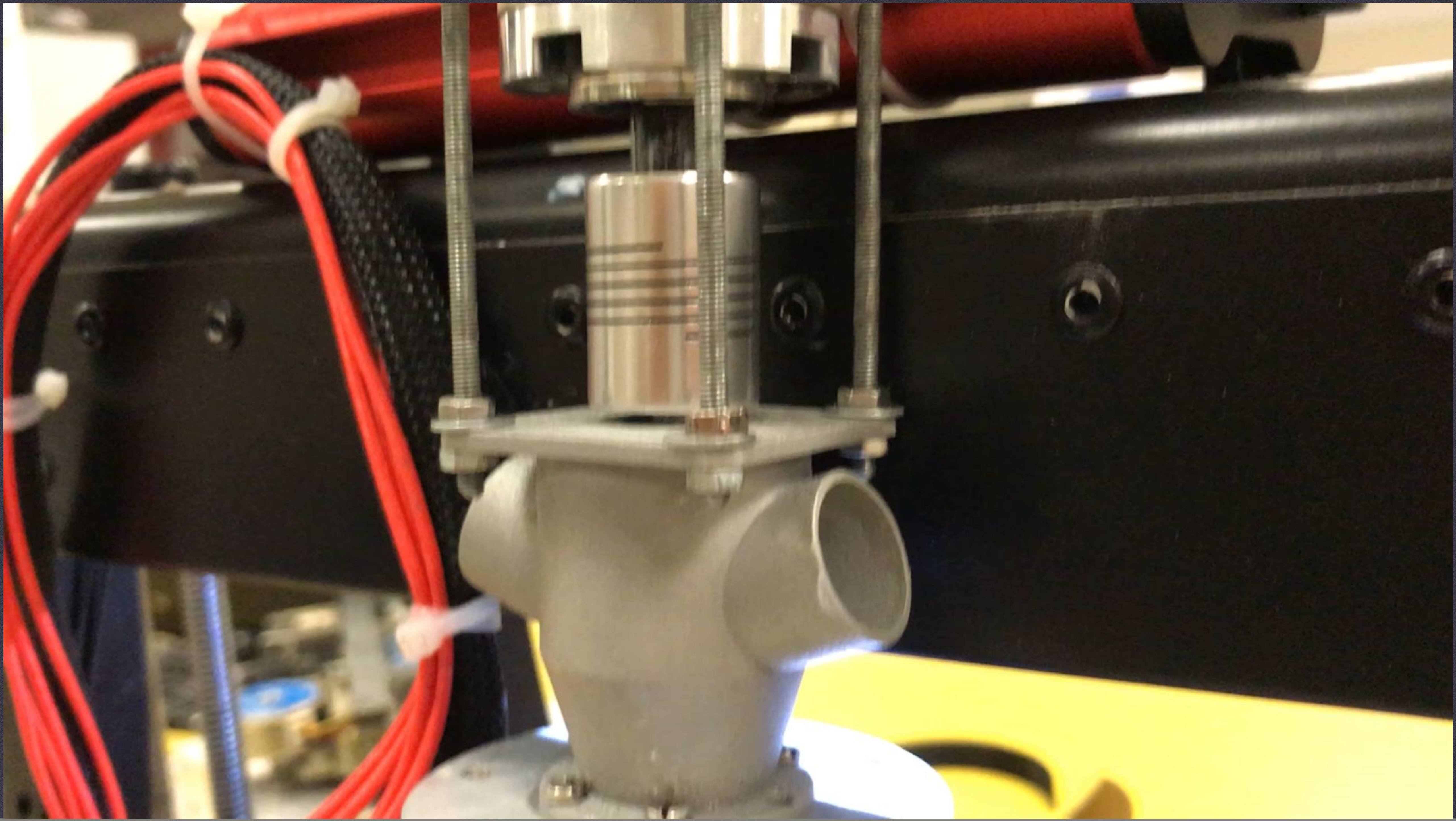
PROJECT

HEATBLOCK

CNC'ED FROM STL (OPENSCAD)

DATE **EARLY 2017**

CLIENT **ICTP SCIFABLAB**



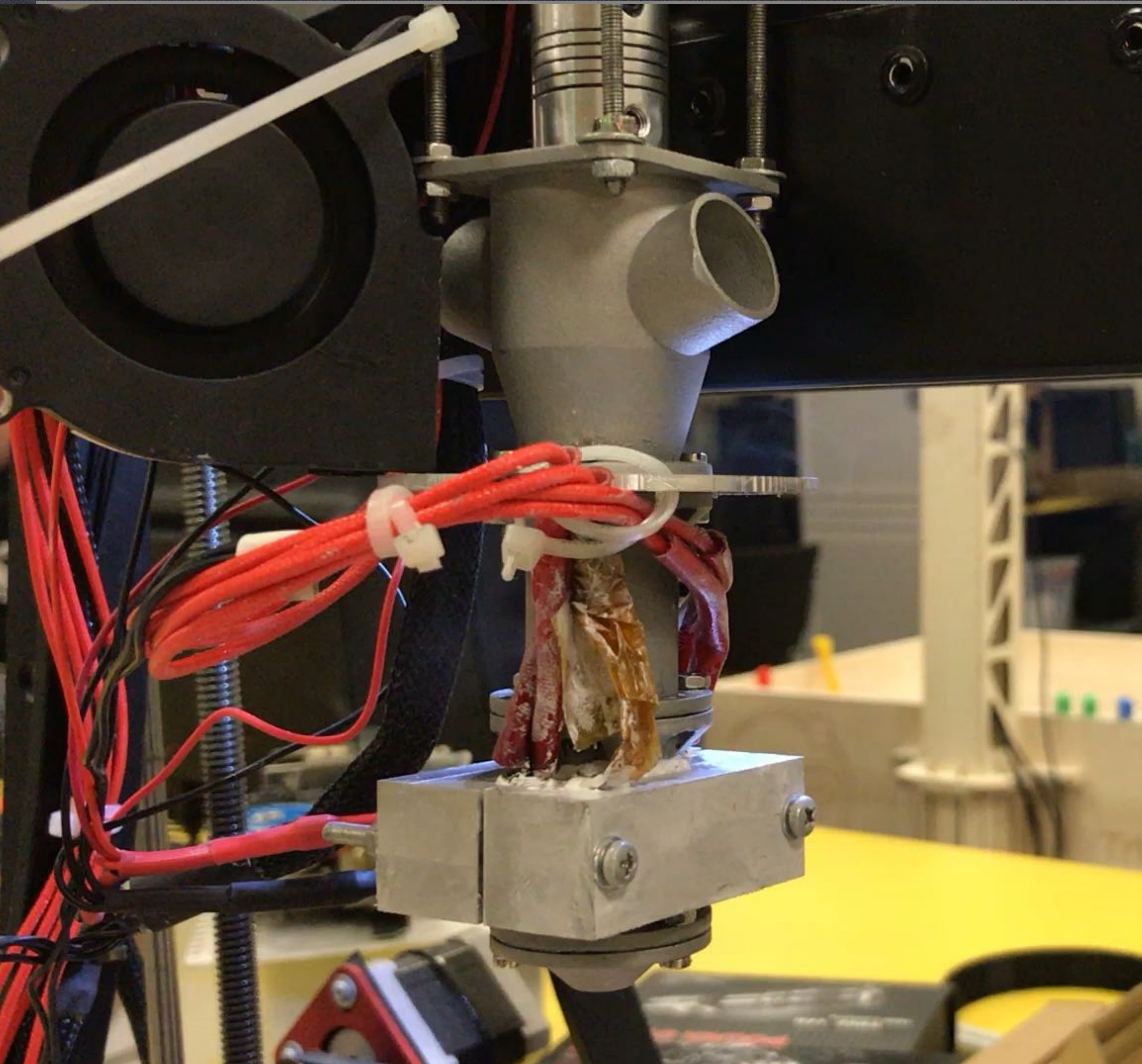
PROJECT

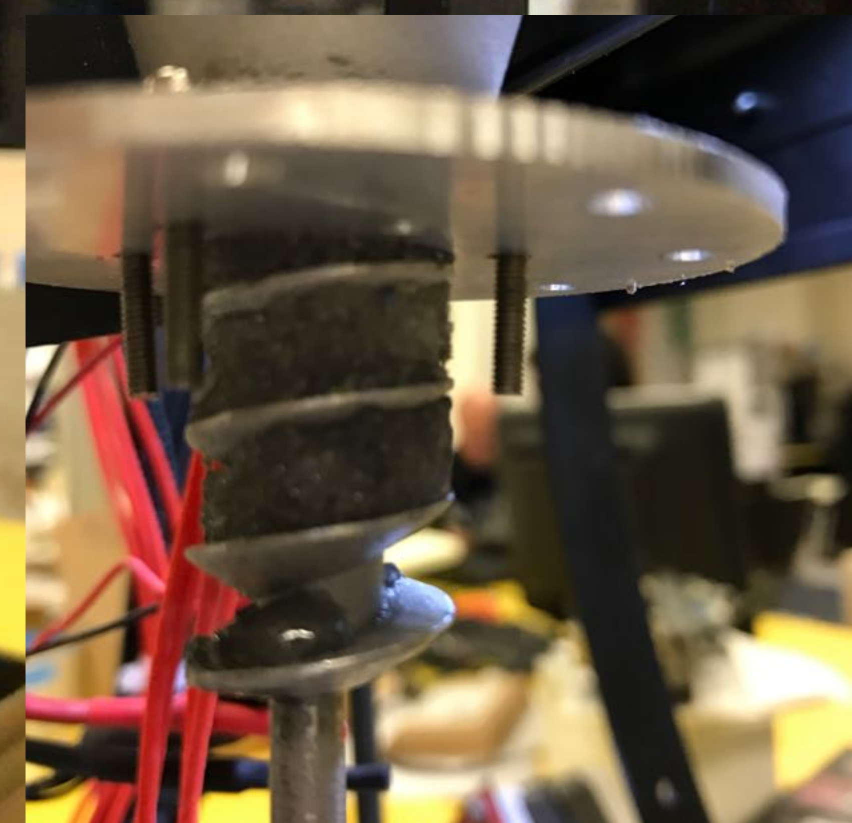
TEST OF OPERATIONS

SINGLE HEATING ELEMENT

DATE **EARLY 2017**

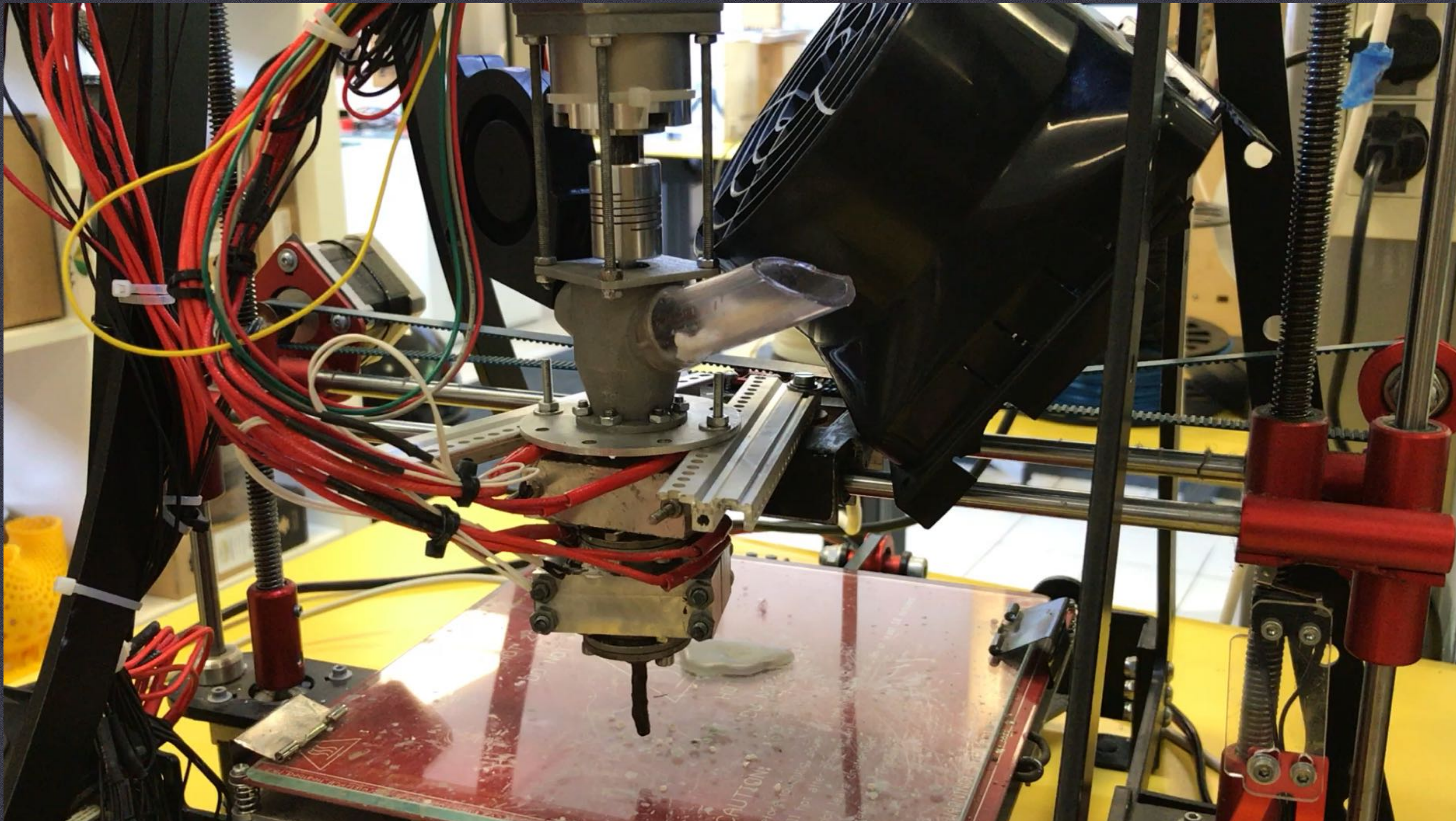
CLIENT **SCIFABLAB**





TEST WITH PLA PELLETS

HEARING IS NOT ENOUGH, WE WILL NEED TO ADD A SECOND HEATING BLOCK TO HEAT THE AUGER SECTION...



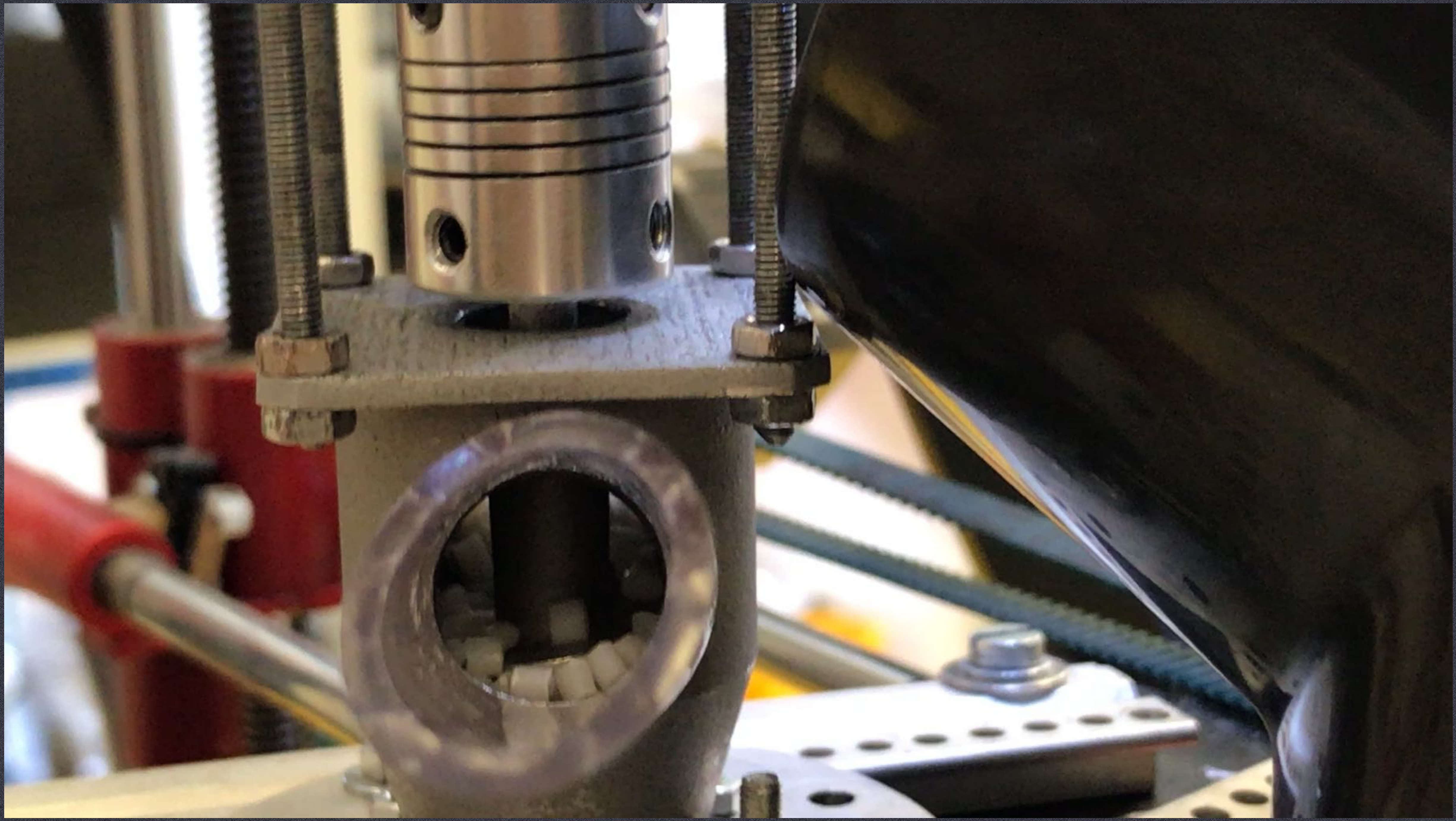
PROJECT

MORE TESTING

DOUBLED HEATING ELEMENT

DATE **HALF 2017**

CLIENT **SCIFABLAB**



PROJECT

IT'S ALMOST WORKING

BUT ONLY FOR SHORT TIMES

DATE **HALF 2017**

CLIENT **SCIFABLAB**

PROJECT

ISSUES WITH THE AUGER SCREW

MORE TESTS AND MODIFICATIONS ARE NEEDED...

DATE **HALF 2017**

CLIENT **SCIFABLAB**