Learn & Fly

Processes and Technologies

Module #4

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4.1 Hot wire foam cutter
Understand how it works

www.learn-fly.eu

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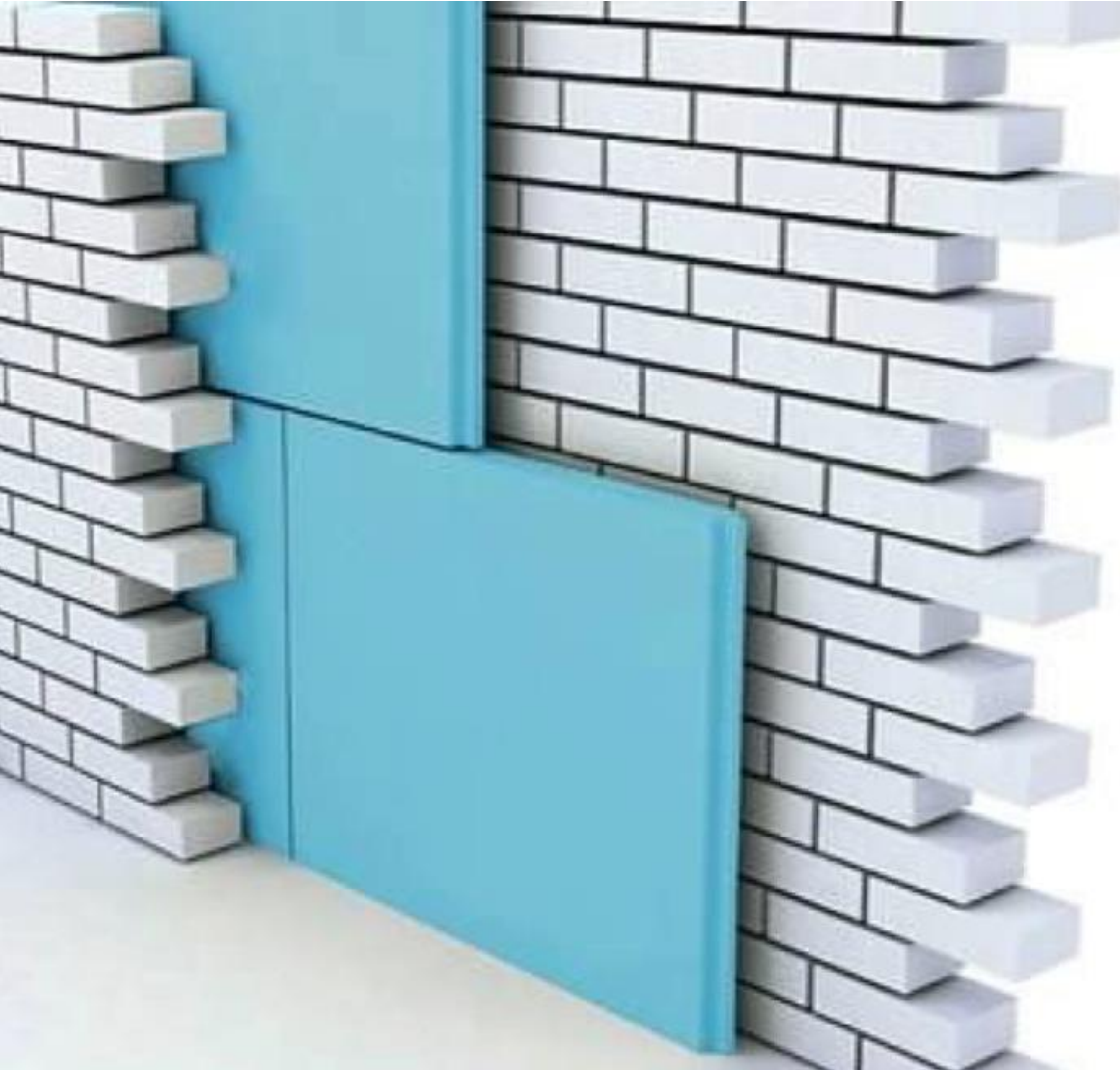

- High density polystyrene is frequently used as insulating material in wall and ruff (wallmate or ruffmate)
- This material is quite appropriate to build models
    - Low density
    - Easy to cut and shape
    - Very easy to buy
      (can be bought at any construction materials store)

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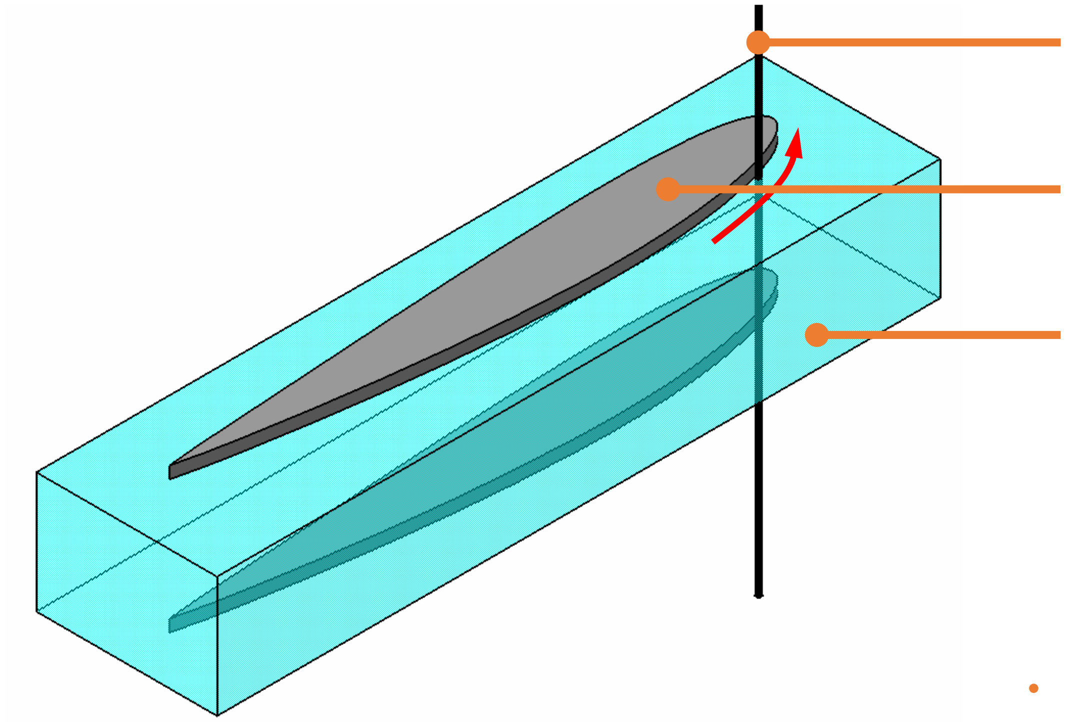

- High density polystyrene can be easily cut with a hot wire
- To obtain the right geometry you need to use a mold

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Manual Hot Wire Foam Cutter

www.proxxon.com

Computer Numeric Control (CNC) Hot Wire Foam Cutter

www.foamlinx.com

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Electrical resistance of a Grill

Electrical resistance of a 3D printer hot bed

- The best way to heat the wire is by passing an electric current through it
- The wire works as an electrical resistance, creating a restriction to the electric current, generating heat (joule heating)

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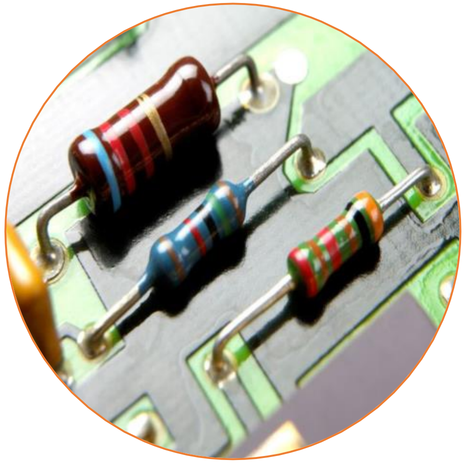
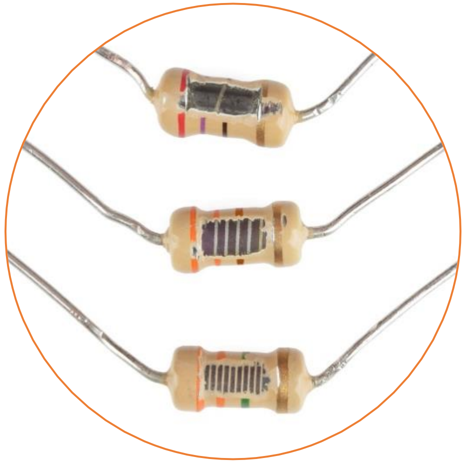


Resistances in
an circuit board



Inside a resistor

Resistor wire

- The resistances, commonly found in circuit boards, have inside a resistor wire
- This resistor wire creates the resistance to the electric current

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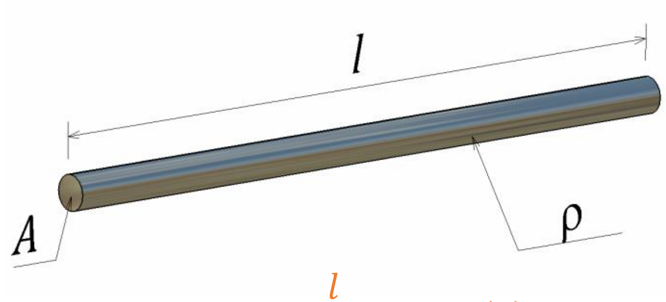
The longer is the wire, the higher is its resistance

If the area of the conductor decreases, the electrical resistance increases

Resistance strongly depends on the material



$$R = \rho \times \frac{l}{A} \qquad (1)$$

ρ – Electrical resistivity of the material
(in S.I. units - $\Omega . m$ – Ohm-Meter)
l – Length of the conductor
(in S.I. units - m – meters)
A – Area of the conductor
(in S.I. units - m^2 – square meters)

In the internet you can find some tools to calculate the electric resistance of a wire by searching for : "electric wire resistance calculator"

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The electrical resistivity is frequently represented by the greek letter ρ and has as International Standard (S.I.) units $\Omega.m$ (Ohm-Meter)

Resistivity of a material is the resistance from face to opposite face of a 1m cube of a material.

	Material	ρ (Ω·m) at 20 °C
Conductors	Silver (pure)	1.55E-08
	Copper (pure)	1.70E-08
	Gold (pure)	2.20E-08
	Aluminium (2014-T351)	5.82E-08
	Zinc (pure)	5.92E-08
	Nickel (pure)	6.40E-08
	Carbon steel (1010)	1.59E-07
	Stainless steel (AISI 304)	7.20E-07
Insulators	Natural Rubber (Vulcanized)	1.00E+14
	Wood (dry)	1.00E+14
	Air (aprox.)	1.30E+14
	Teflon	1.00E+23

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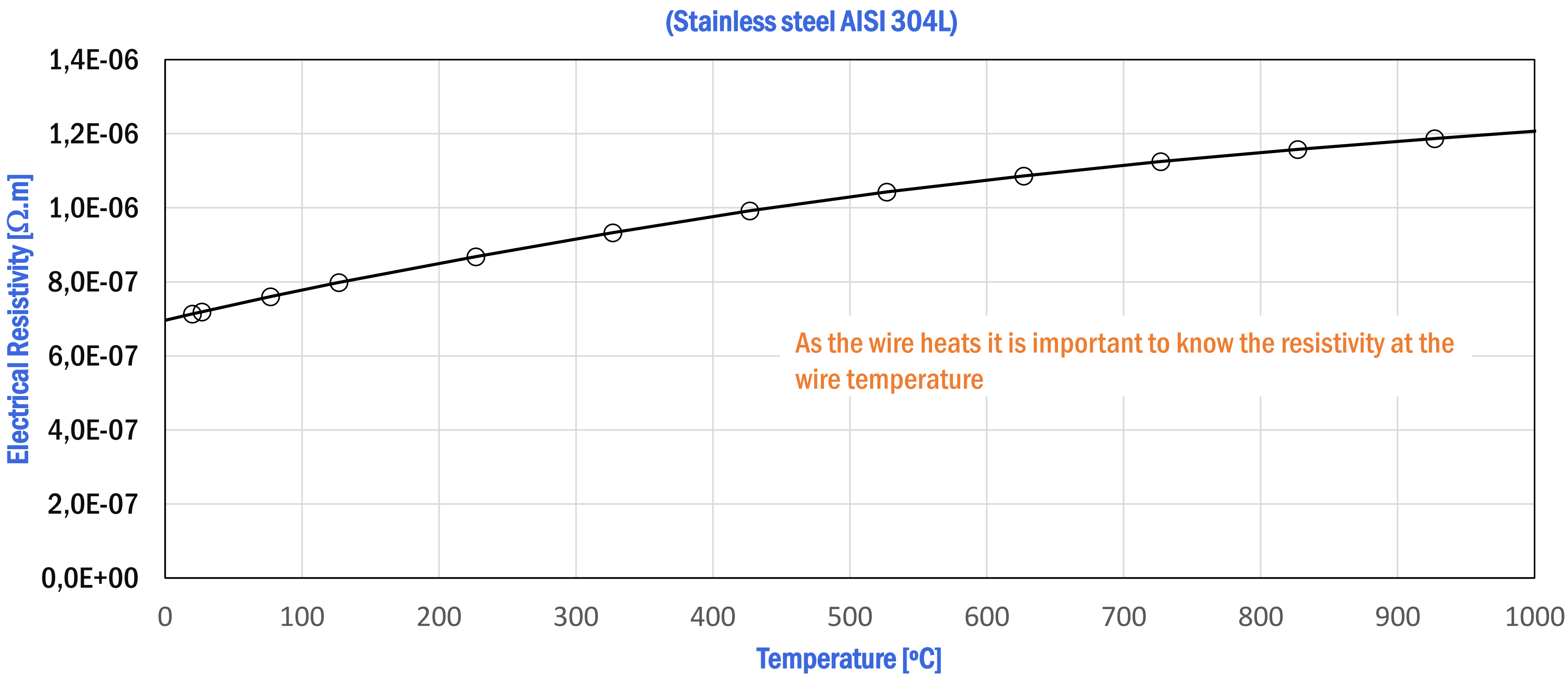

Ho, C. Y., Chu, T. K., "Electrical resistivity and thermal conductivity of nine selected AISI stainless steels", CINDAS Report, 1977

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4.2 Design your own hot wire cutter

How to make a machine to cut high density polystyrene foam

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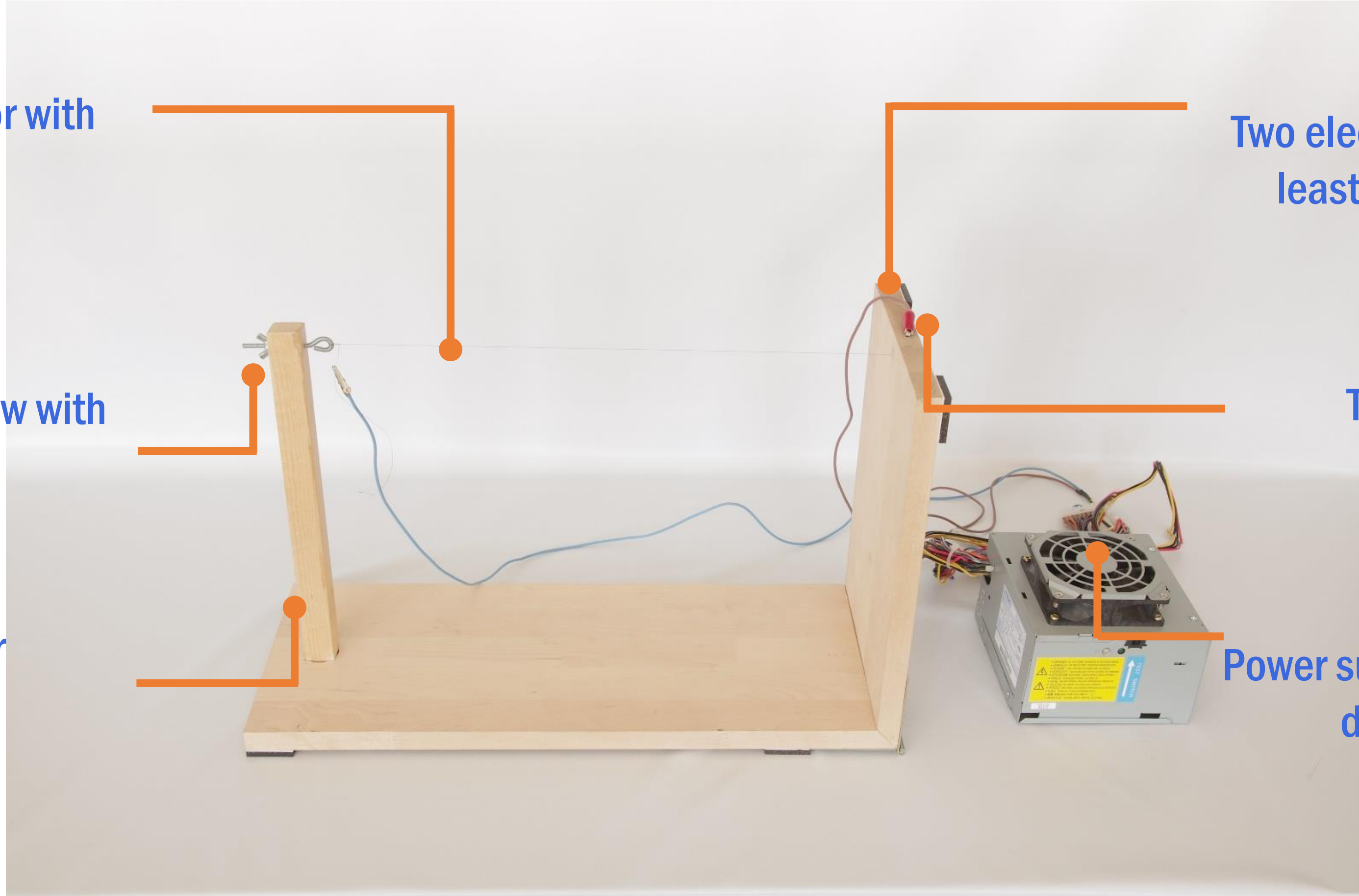

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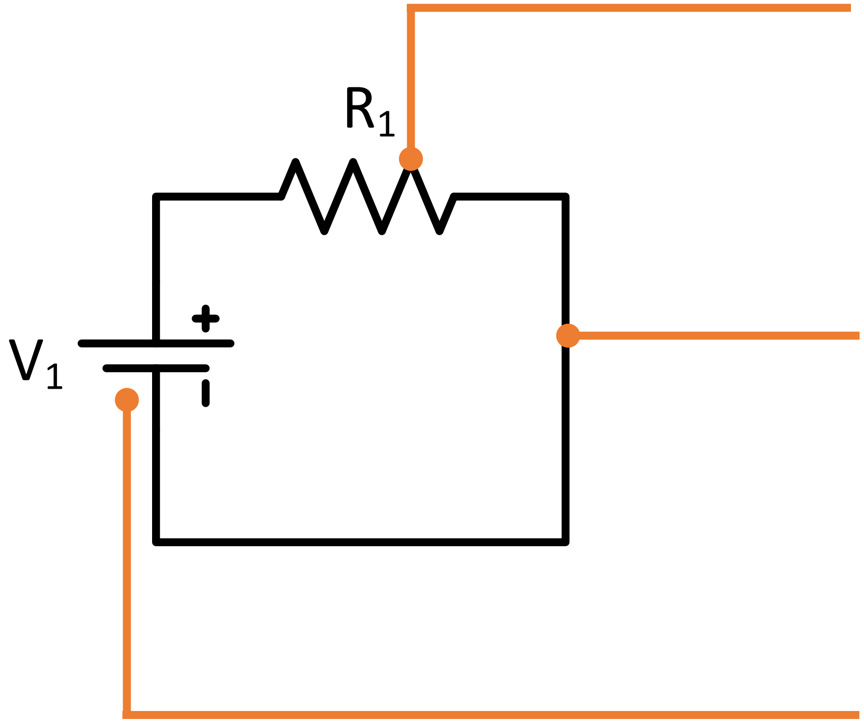
- To select the hot wire it is necessary to understand the electric circuit
- The resistance will convert power into heat, thus if a wire is used as a resistor it becomes hot and can cut the foam



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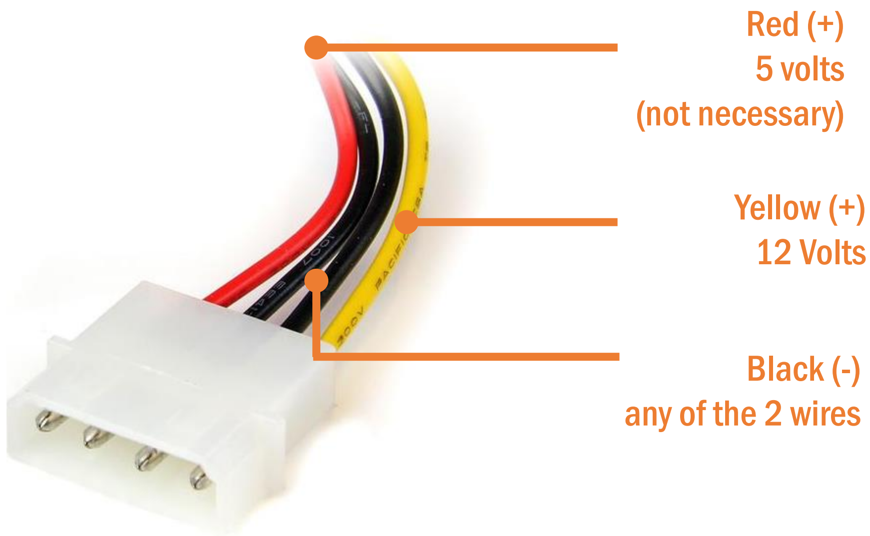
- The temperature required to cut high density polystyrene is about 200ºC
- To reach the ideal temperature a wire with about 0.5 meters must dissipate a least 24 Watts power.
- The power supply of a desktop computer has an exit with 12 Volts in the 4 pins molex connector (between yellow (+) and black cables (-)) which can be used to heat the wire.



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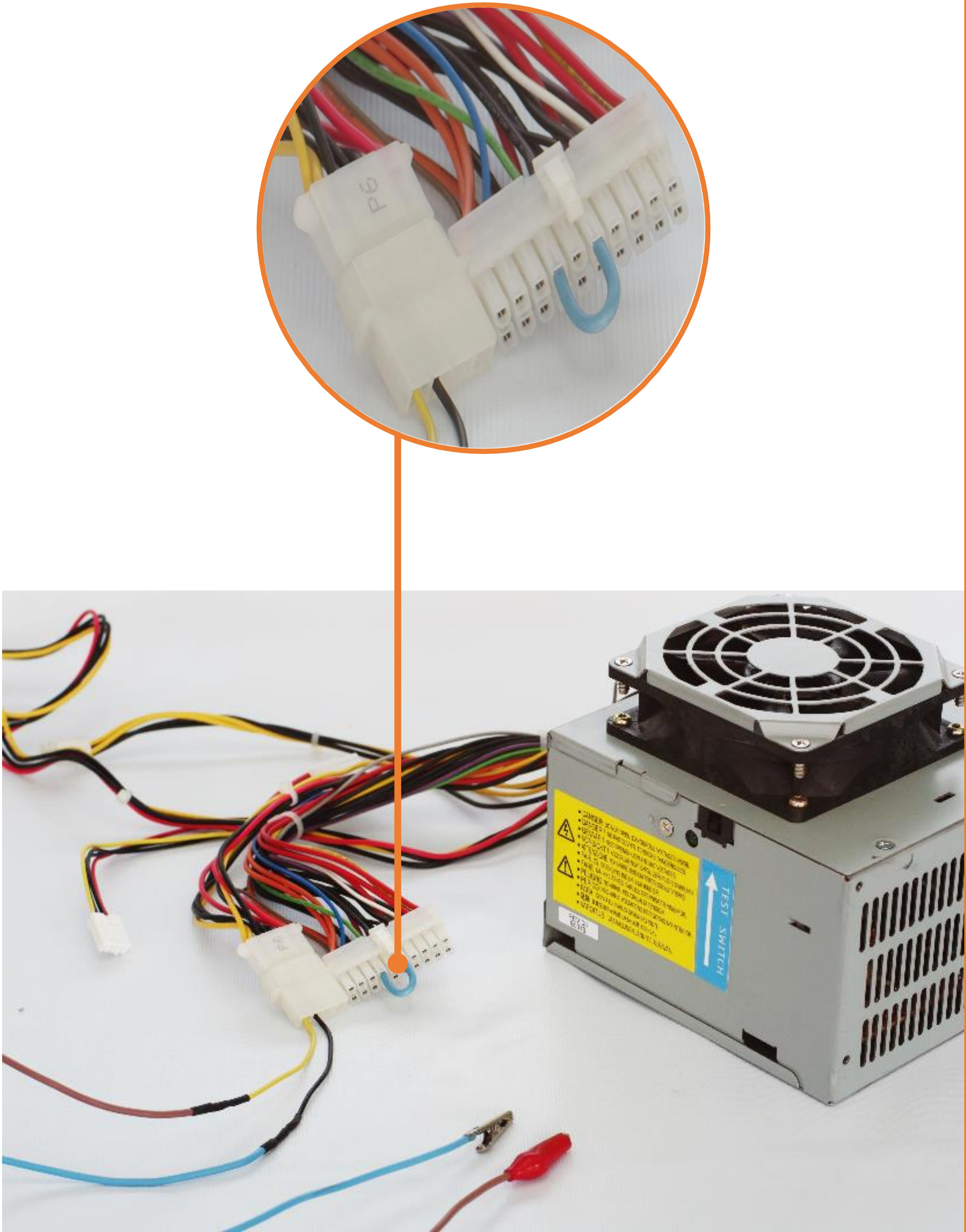

- Get the 12 Volts signal from yellow (+) and black (-) cables in the 4 pins molex connector
    - Attach two cables with alligators on the end.
    - It does not matter the side of the hot wire where you connect the (+) or (-).
- Shot circuit in the large plug the green wire with one black wire
    - This is required to power on the power supply (is like switching on the computer)
    - You can use a paper clip or a piece of wire to do that
- Find more in youtube

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The right wire material and diameter must be selected. If these are wrong it may not heat enough or heat too much and break the wire. The electrical power will be converted to heat in the resistance (wire) according to:

$$P = I^2 \times R \qquad (2)$$

- P – Power (in S.I units – W – Watts)
- I – Current (in S.I. units – A - Amperes)
- R – Electrical resistance (in S.I. units – Ω – Ohm's)

To obtain the current the Ohm's Law can be used

$$V = R \times I \qquad (3)$$

- V – Voltage (in S.I. units – V - Volts)

Putting together we obtain

$$P = V^2/R \Rightarrow R = V^2/P \qquad (4)$$

With last equation (4) the required resistance of the wire to obtain the power of 24 watts (4.2.3) is:

$$R = 12^2/24 = 6\,\Omega \qquad (5)$$

Knowing the right resistance, the remaining properties of the wire can be obtained using eq. (1) from section 4.1.5:

Material of the wire (has to do with the electrical resistivity)

Length of the wire

$$R = \rho \times \frac{l}{A} \qquad (1)$$

Diameter (has to do with the cross sectional area A)

$$A = \pi . D^2/4 \Leftrightarrow D = \sqrt{4.A/\pi}$$

D is the diameter of the wire

π = 3.1416 is the relation between the perimeter and the diameter of a circle

To avoid a very low sectional area, a very resistive but conductive material, such as stainless steel, must be selected (section 4.1.5) The resistivity has to be obtained at the wire temperature (about 200ºC), from the last figure provided in section 4.1.5

$$\rho \cong 8.5 \times 10^{-7}\ \Omega.m$$

As an example, having a length of 0.5 meters, the area can be obtained from equation(1)

$$A = \rho \times \frac{l}{R} = 8.5 \times 10^{-7} \times \frac{0.5}{6} = 7.083 \times 10^{-8}\ m^2$$

And the diameter:

$$D = \sqrt{4.A/\pi} = \sqrt{4 \times 0.177 \times 10^{-6}/3.1416} = 0.0003\ m = 0.3\ mm$$

- Required wire
  - Stainless steel wire
  - Length about 1 meter (0.5 m + wire to tie)
  - Diameter about 0.3 mm
- Steel string wire (which is generally made from stainless steel) is very easy to find in instruments music stores (used as electric guitar strings)
  - Ask for plain steel string wire
  - Request the diameter in inches (in) (imperial units of length, quite used in UK and US)
    - 1 in = 25.4 mm
    - For a string with 0.3 mm is $\frac{0.3}{25.4} = 0.0118$
    - Should be selected the closest available diameter, size 0.013 in.

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The wire will increase length with temperature (termal expansion), loosing its tension. Next equations gives how much it will allongate.

Material	α (/°C) at 20 °C
Aluminium (2024-T351)	22.9E-06
Steel (AISI 1020)	11.70E-6
Titanium (Ti-6Al-4V)	8.60E-06
Stainless steel (AISI 304)	17.3E-07

Example of the coefficient of thermal expansion for some structural materials (www.matweb.com)

Elongation of the wire

Length of the wire

$$\Delta l = \Delta T . \alpha . l_0 \quad (6)$$

Thermal variation
(200ºC – 20º) = 180ºC

Coefficient of thermal expansion (material parameter)

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For the example provided the wire will elongate:

$$\Delta l = \Delta T . \alpha . l_0 = 180 \times \mathit{17.3E{-}07} \times 0.5 = 0.0001557\, m = \mathbf{0.1557\, mm}$$

$$\Delta T = 200°C - 20°C = 180°C$$

Room temperature

Stainless Steel

Wire with 0.5 m

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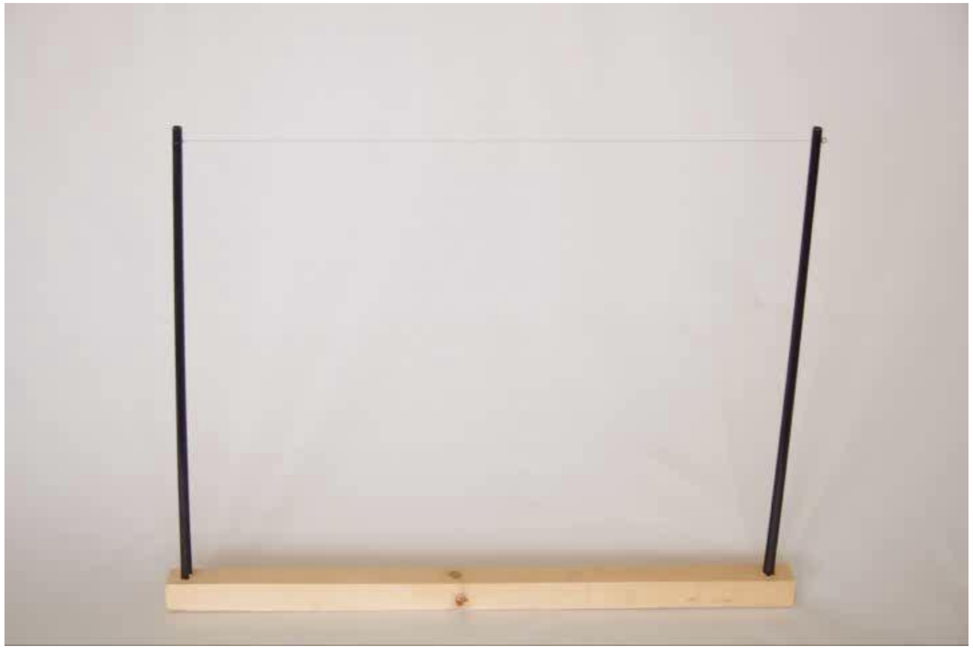
To avoid the wire from loosing tension the structure must be flexible (not to stiff) or it must be added a Spring



Flexible structure

Stiff structure

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Materials

Supplied with the Learn&Fly kit

To ends of fishing rod with aprox. 0.4 m or glass fibber tubes ①

Bought from a construction materials store

One slat of wood with aprox. 0.6 m. Make two holes at the end with a diameter of the fishing rod and slightly inclined to ouside ②

Bought from a music store

One steel string wire with size 0.010 in ③ (recommended to by more)

Bought from electric components store

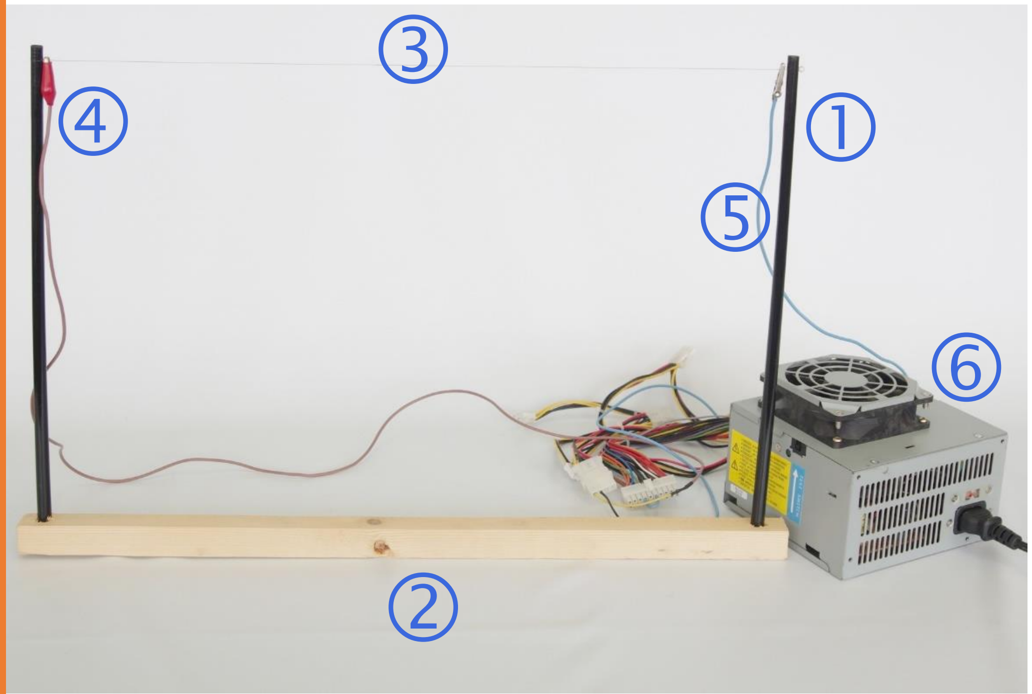
Two alligator clips④

That you probably have at home or in your school

Two electric wires with 1 m to connect to the power supply with the alligator clips at the end. ⑤

One Power supply from an unused old computer ⑥

It is not important the side of the positive or negative (ground connectors)



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4.3 Additive Manufacturing

Improve your project using new technologies

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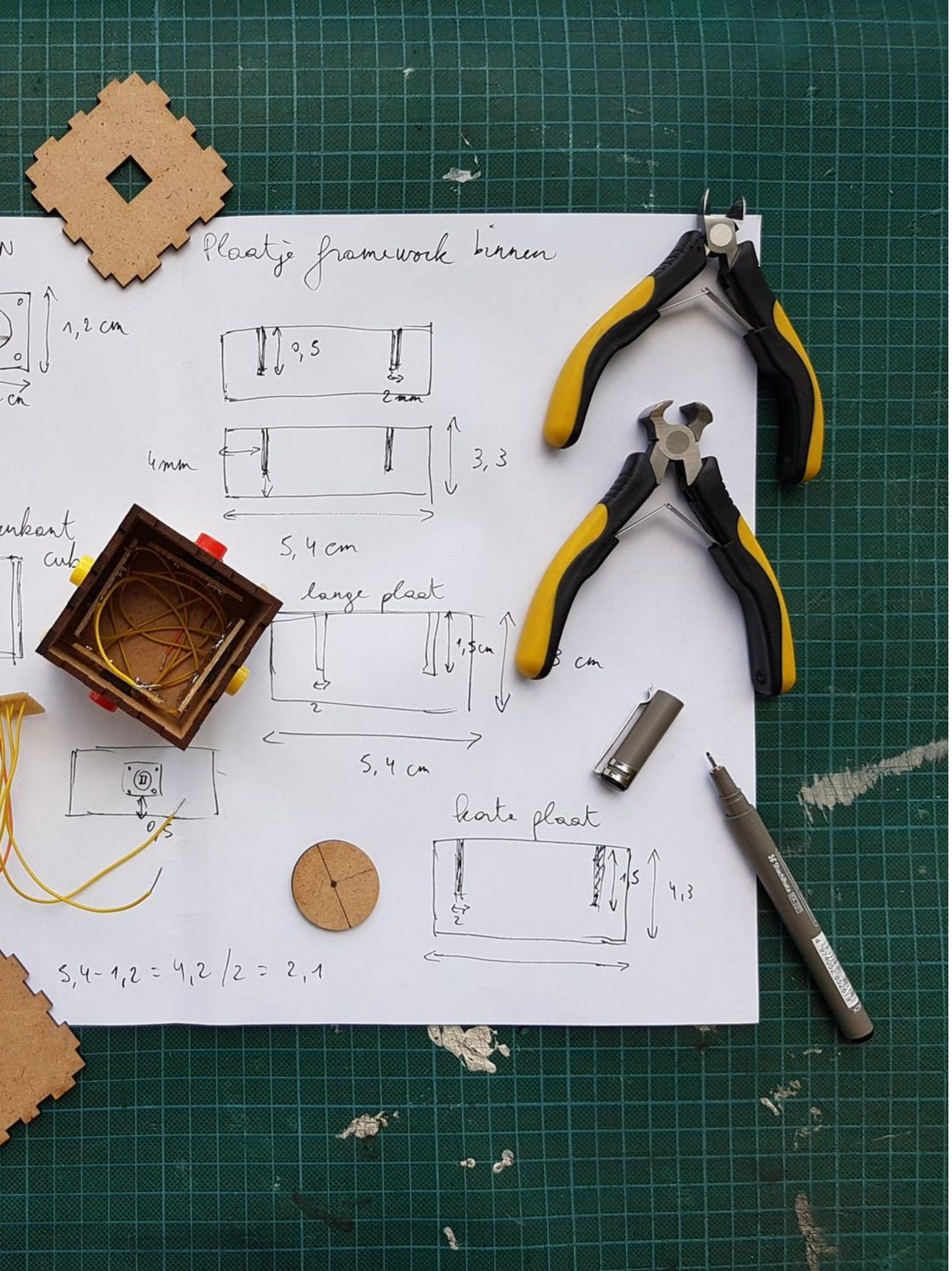

- Additive Manufacturing (AM) is new manufacturing technique able to quickly produce physical models directly from 3D drawing (CAD data)
    - Also known as: 3D Printing, Rapid Prototyping
- Parts are built layer by layer in a 3D a printer
- AM is nowadays being used to fabricate end-use products in aircraft, dental restorations, medical implants, automobiles, prototypes, molds and even human organs.

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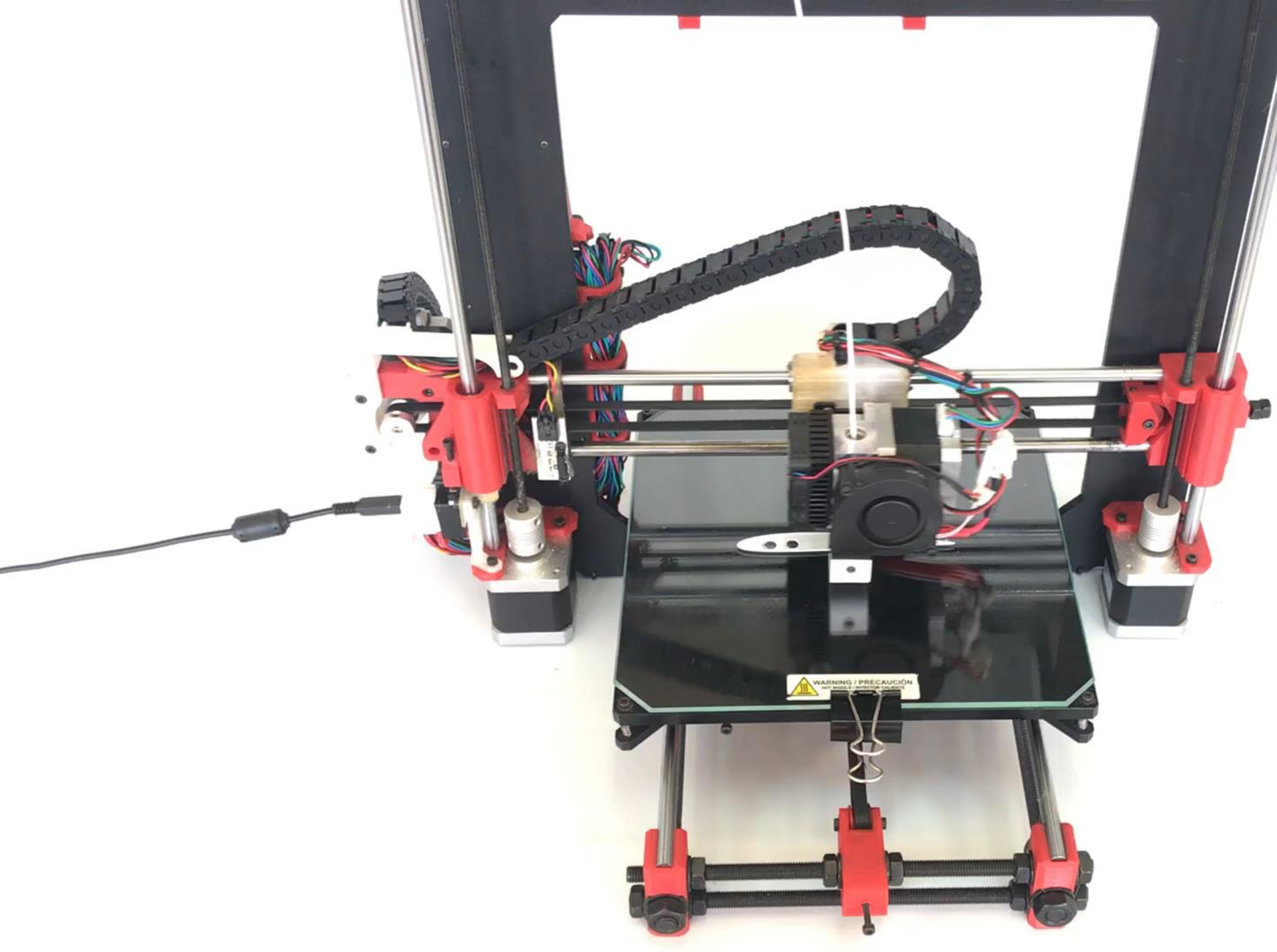
4.3.2 Model wing rib being printed



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Almost anything...

Ship Part www.nlr.org/

Prosthesis //all3dp.com /3d-printed-prosthetic-leg-uae/

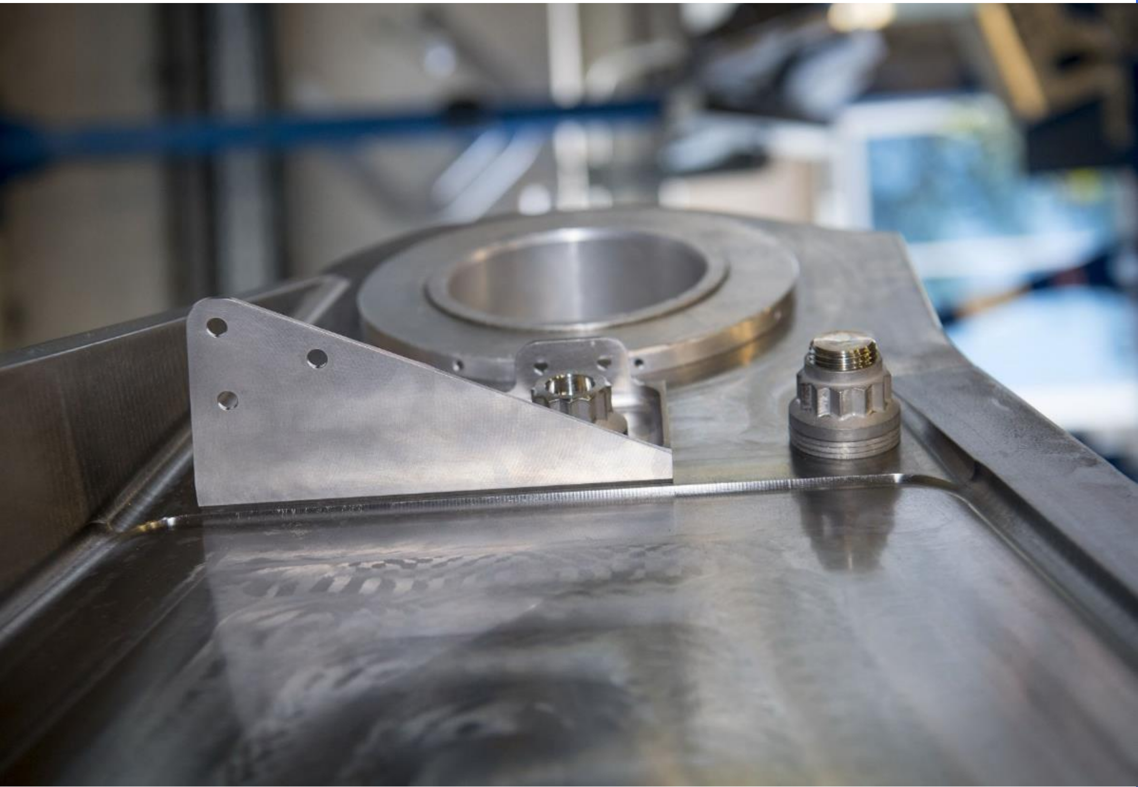
Motorcycle Frame www.treehugger.com/

Tyre Prototype*

Baby Car Seat Prototype*

Complex geometries www.re3dtech.com/

Jewelry www.3dnatives.com/



“Airbus completed for the first time the installation of a titanium 3D-printed bracket on an in-series production A350 XWB. The bracket, built using additive-layer manufacturing (ALM) technologies (also known as 3D-printing), is part of the aircraft pylon, the junction section between wings and engines.”

www.airbus.com

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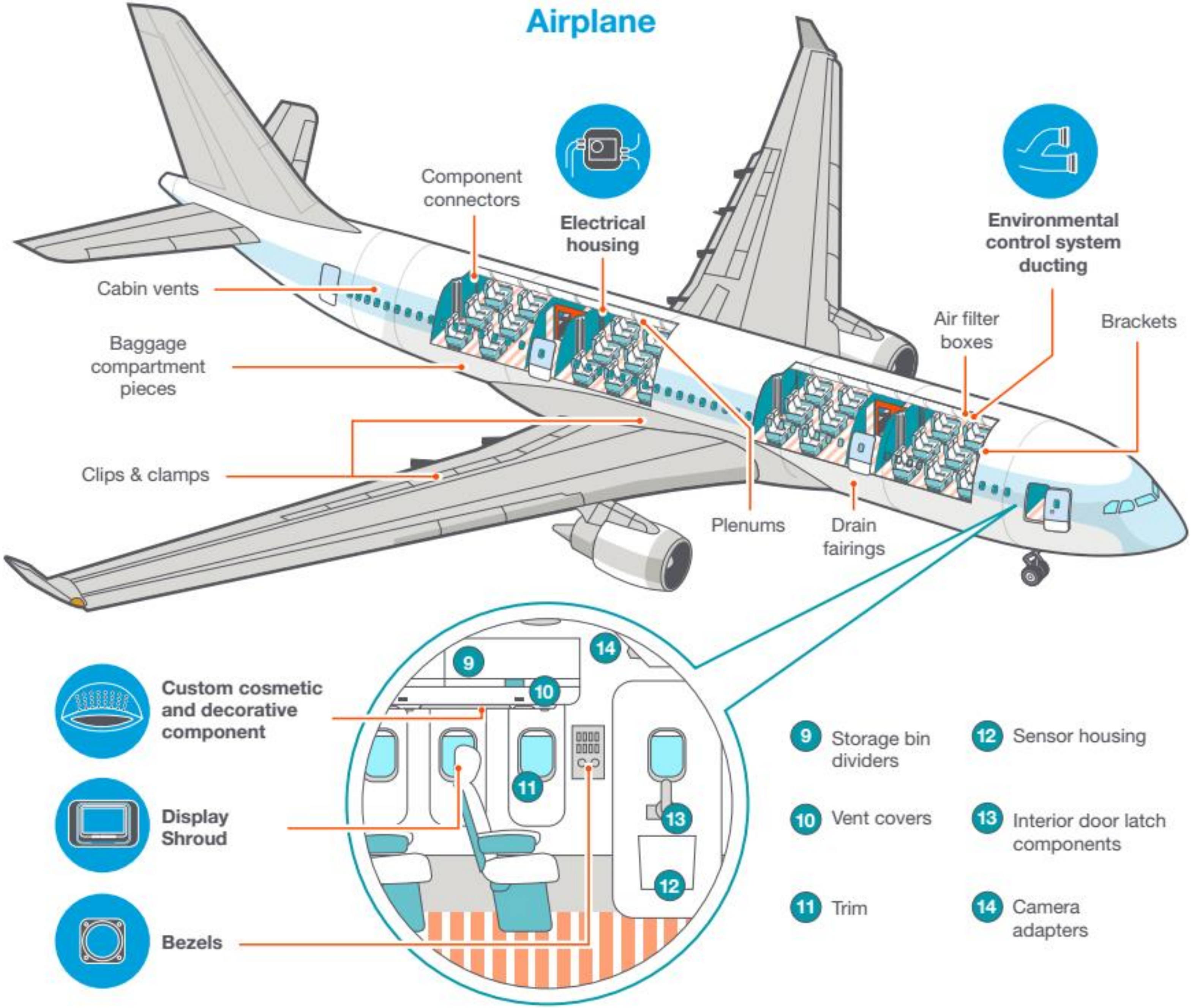
www.stratasysdirect.com/industries/aerospace

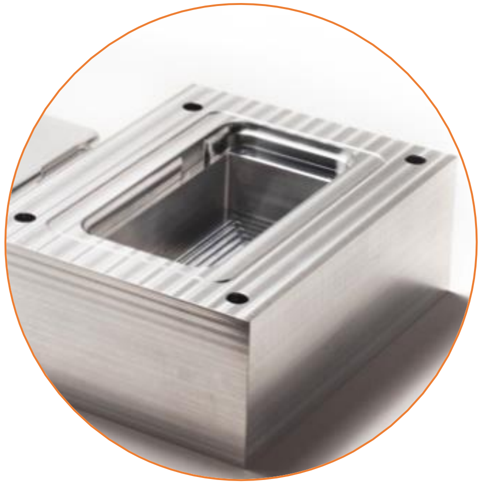


Additive Machining

(material is added)

1-100 parts

Parts ready in 1-3 days



CNC machining

(material is removed from a block)

1-100 parts

Parts ready in 1-3 days

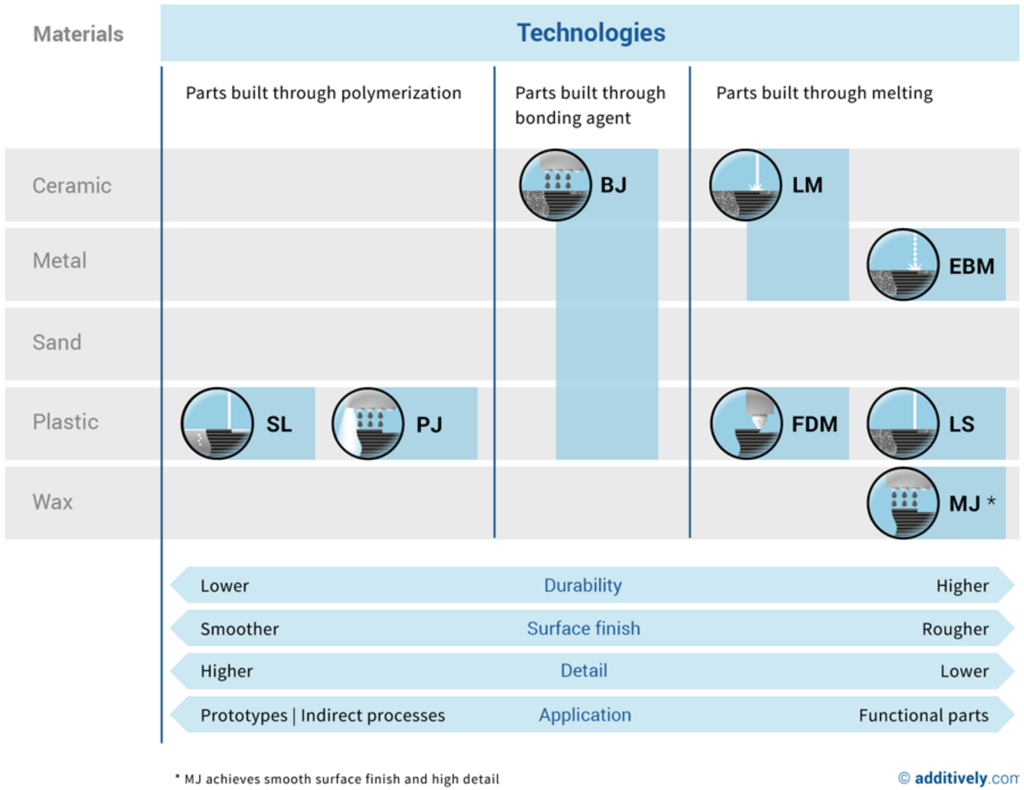
Injection molding

(material is injected in a mold)

>500 parts

Parts ready in 2-8 weeks

- Fused Deposition Modelling (FDM)
- Binder Jetting (BJ)
- Electron Beam Melting (EBM)
- Hybrid Processes (HP)
- Laser Melting (LM)
- Laser Sintering (LS)
- Material Jetting (MJ)
- Photopolymer Jetting (PJ)
- Stereolithography (SL)



www.additively.com/en/learn-about/3d-printing-technologies

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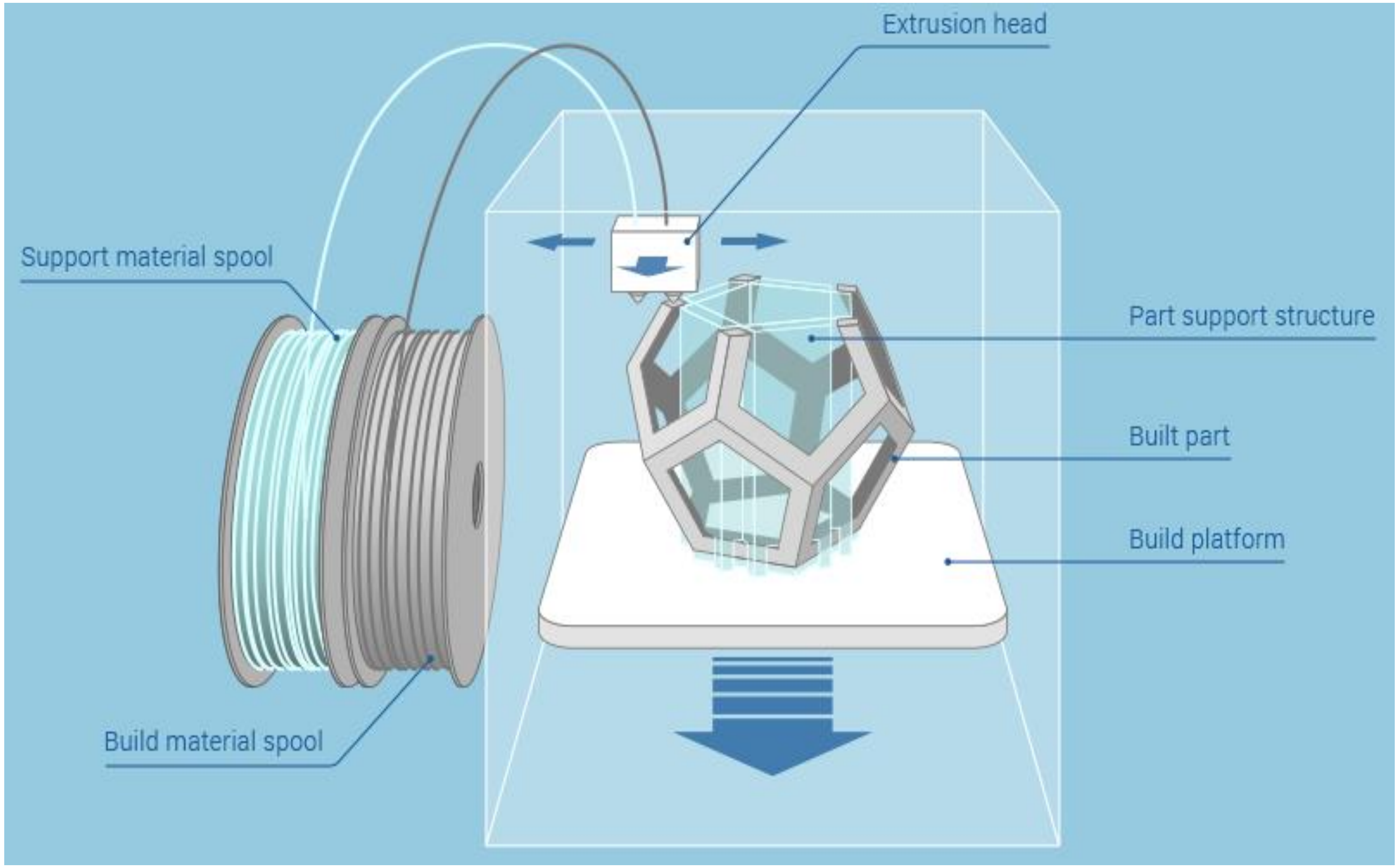
- FDM is Presently the most popular consumer-level 3D printers
- The filament is melted, extruded through a nozzle into a build platform, where it cools and solidifies.
- The part is built layer by layer.



www.additively.com/en/learn-about/3d-printing-technologies

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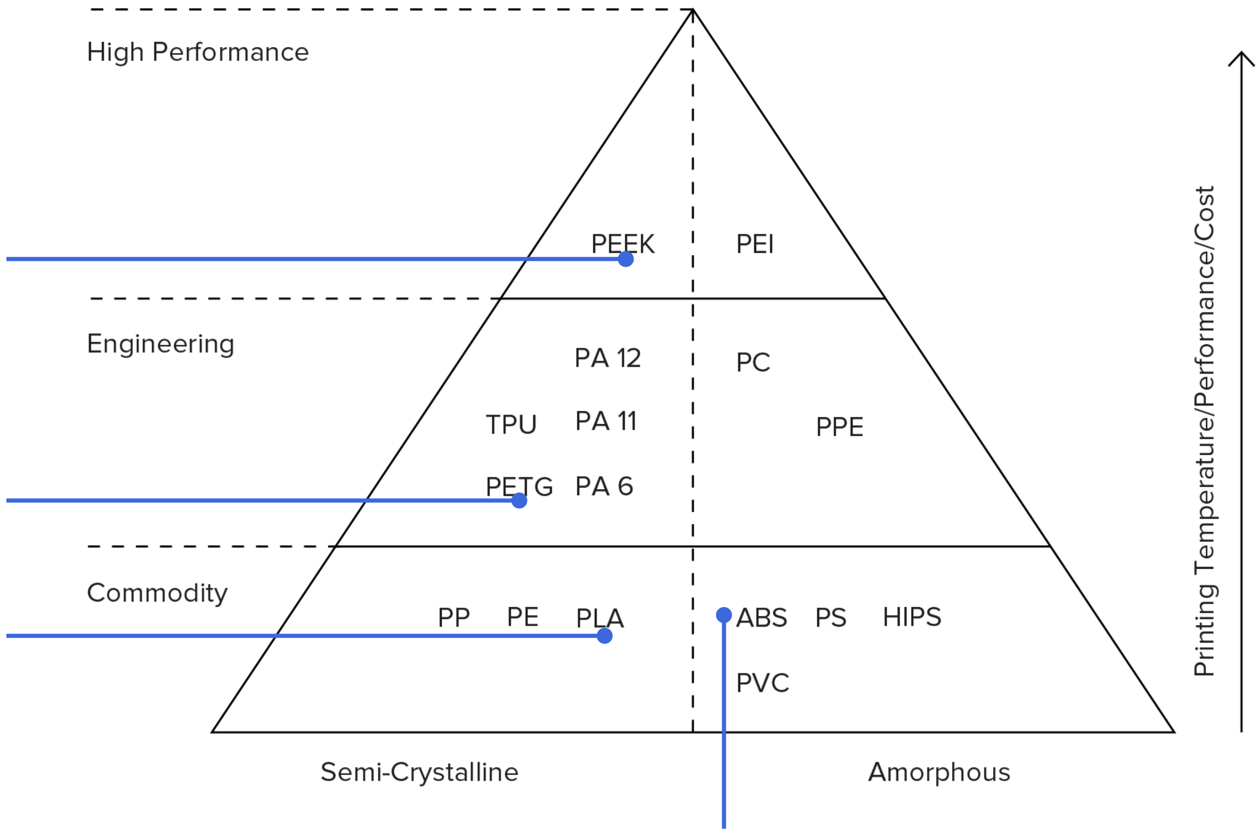
PEEK
+ Excellent fire, chemical and mechanical resistance
- High cost

PETG
+ Low price and good strength
+ Easy to print

PLA (the most popular)
+ Low price
+ Very easy to print
- Low temperaute resistance



ABS
+ Good strength
- Susceptible to warping

www.3dhubs.com

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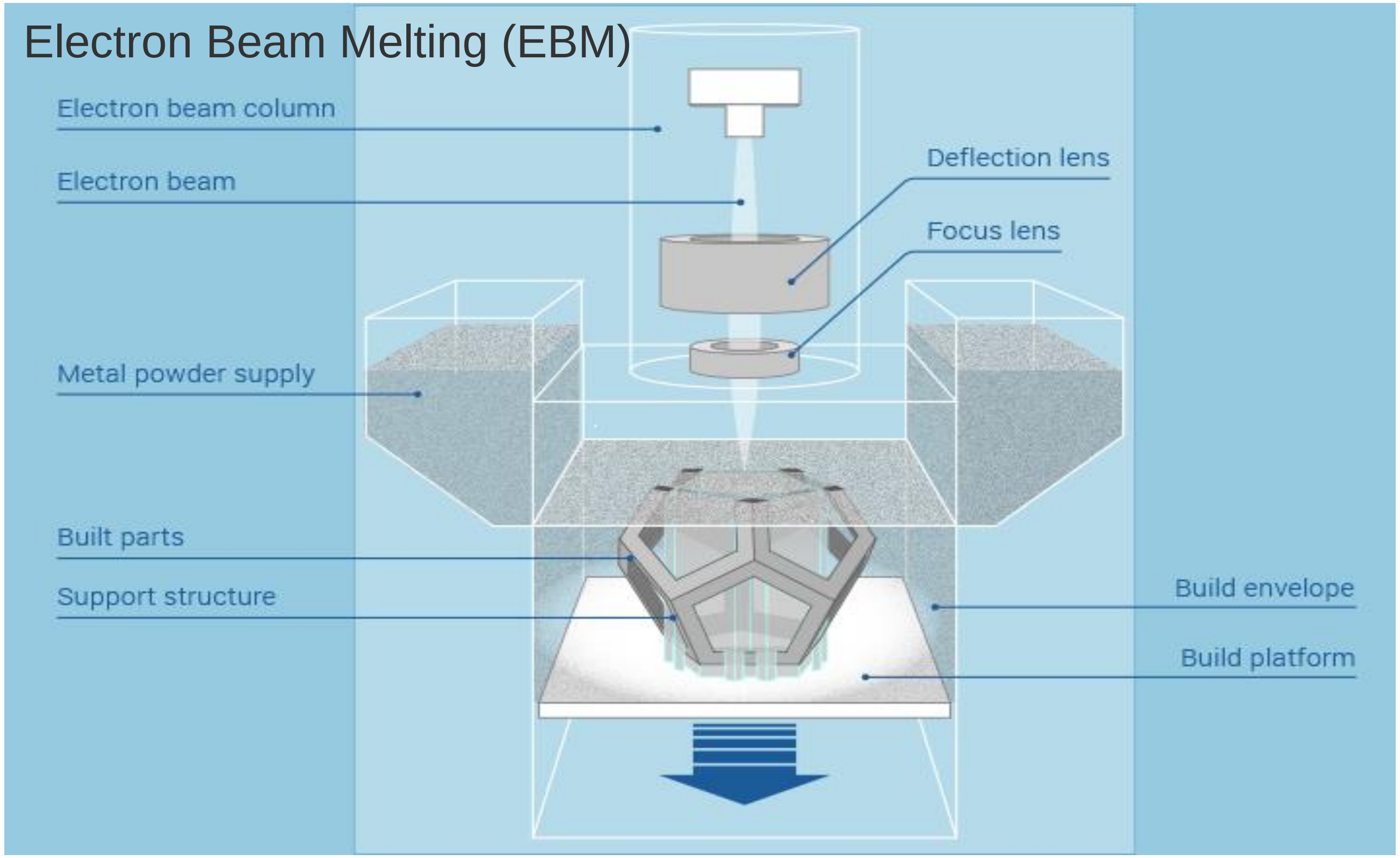
- The other technologies for 3D also build parts layer by layer, one layer at a time
- However different methods are used to feed material or to do polymerization like: extrusion, vat photo, powder bed fusion, binder jetting, sheet lamination, material jetting or directed energy deposition



www.additively.com/en/learn-about/3d-printing-technologies

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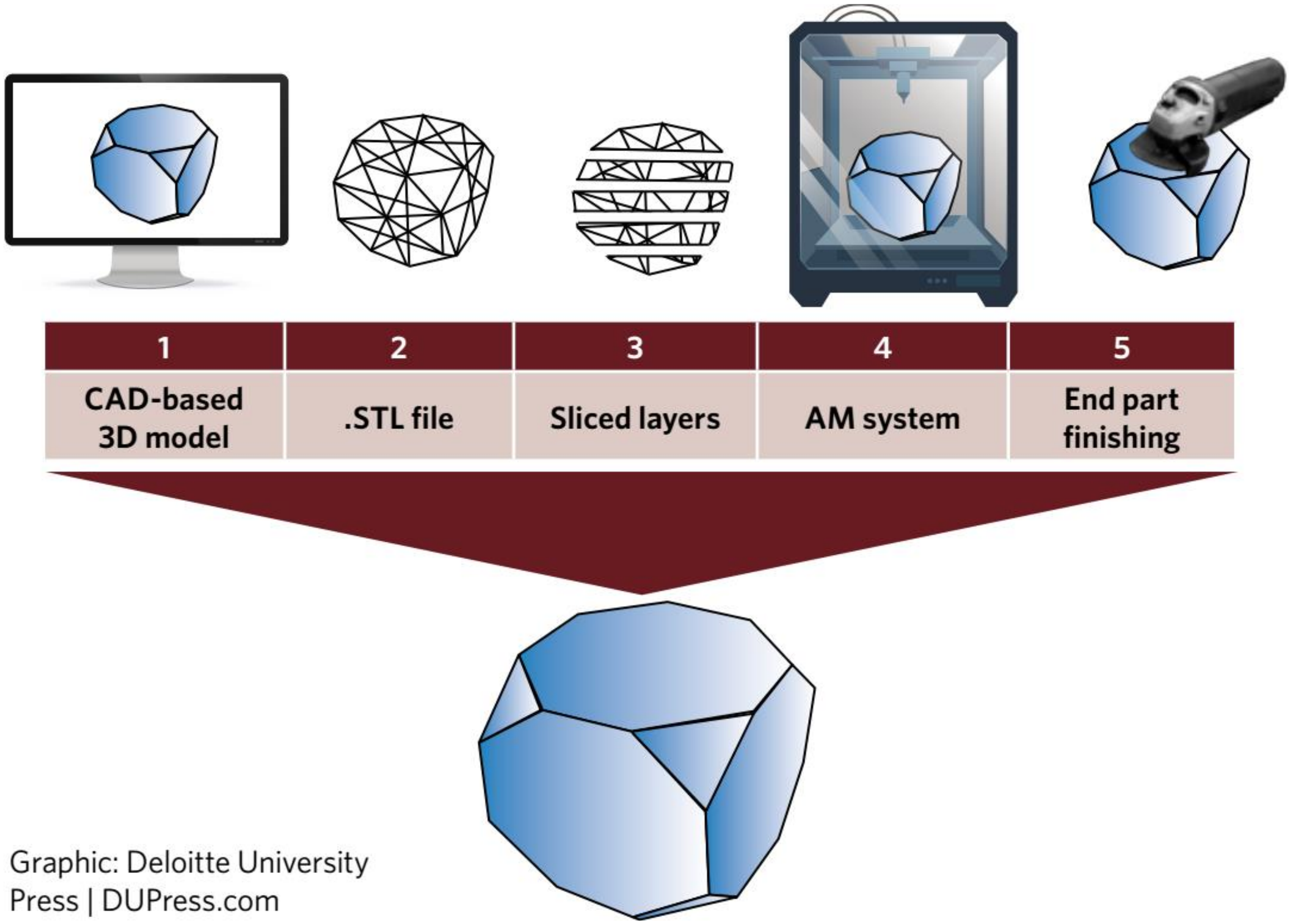
- 1st Use a 3D modelling software (CAD) to create the virtual part or get it from a database (geometry to be printed)
- 2nd Save the part in a standard 3D format (.STL, or other)
- 3rd Use software to slice the model and generate "G codes" and send the code to the printer (SD card or Wi-Fi)
- 4th Print the part in a 3D printer
- 5th Finish the part



Graphic: Deloitte University Press | DUPress.com

https://www.additively.com/en/learn-about/3d-printing-technologies

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- The first main step to 3D print a part is to craft the model
- It is recommended to use a CAD software to design the part
    - In section 5.5 (3D modelling software) some information can be found about software available and the principles to create a model
    - Learning a 3D CAD software is not an easy task. If you are willing to learn you will find a lot of documentation an tutorials that will help
- You can also find lots of CAD models already made.

Some of these free sources are:

Thingiverse

YM

Cults.

GRABCAD

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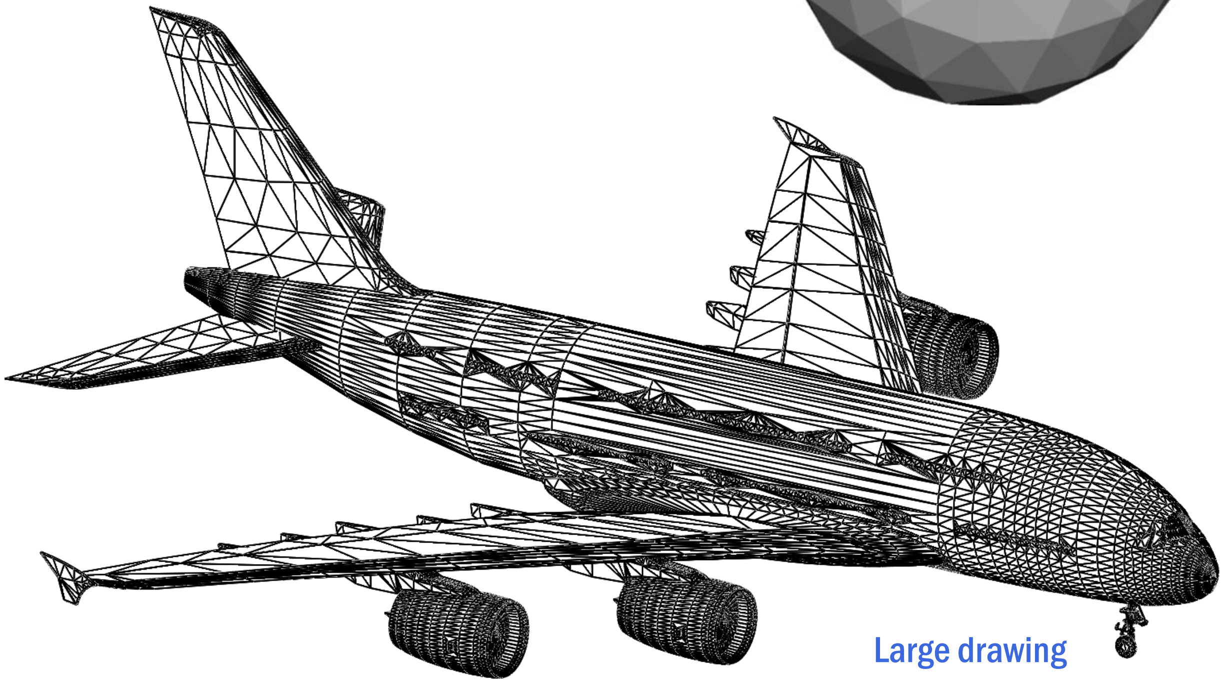
- The second step is to save your drawing with in a standard format (.stl)
- This is the most often used format to transfer the CAD model to a slicing software
- This format approximates the surfaces of a solid model with 2D triangles
- There are other formats (like .obj or .3wf), not so frequently used, that can include additional information such as color, material etc
- All CAD systems are capable of producing an STL file.
  These files has the extension (.stl)

STL model of a Sphere



Large drawing

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- Third, slice your model with software
- The slicing software prepares the model to print, generating a “g code” with instructions for the printer to print the model
- The part is divided in several slices (generally with about 0.05 mm to 0.2 mm thickness). You can think of every slice as a 2D piece of paper, which if joined together to form the

Slicing 3D Model Printing each slice

- Most popular slicing software
  - Free software
  - Commercial software

- **G-Code example**

```
G28 X0 Y0        ;move printed head to the X/Y origin (Home)
G28 Z0           ;move to the Z origin (Home)
M109 S205        ;heat the filament up to 205ºC
G1 Z5.0 F1200    ;move Z to position 15.0 mm
G1 E20 F200      ;extrude 20mm of feed stock at 200mm/min
G1 Z0 F1200      ;move Z to position 15.0 mm at 1200 mm/min
G1 X10 Y10       ;move to coordinates X 10 mm and Y 10 mm.
... (thousandths of lines)
```

Example for a BQ Prusa i3 3D printer

- The fourth step is to print your part
- Depending on your printer, usually you need to put the file in the printer through an SD card, USB or wifi connection
- In general all printers have an intuitive menu system to allow to select the file and print it

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At the end, depending on your application, you need to finish the part

- Remove supports
- Remove any layers that were necessary for build plate adhesion
- If the part is to be assembled, sometimes it is necessary to set holes and other elements tolerances
- Polish the part with sand paper
- Do some painting or other end finishing

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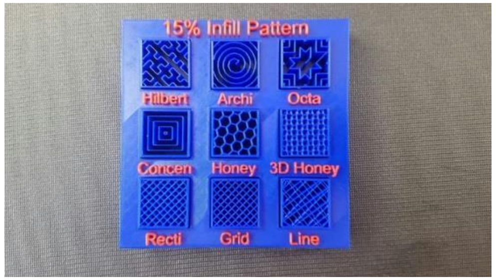
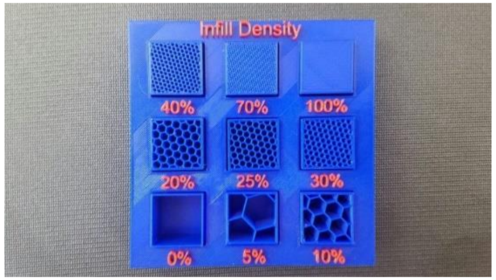
- Lets print a tiller of an AirBus A320 for a flight simulator. The tiller is used by the pilots to control the direction of airplane an to keep it aligned with the runway centerline during takeoff and landing.
- This part is quite complex to produce by conventional manufacturing techniques

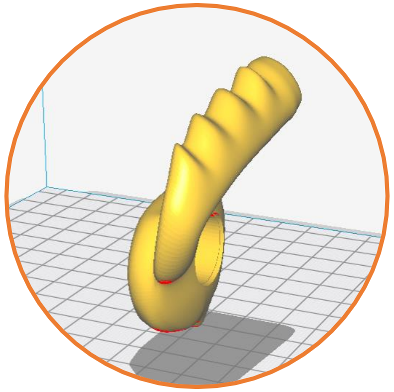
- infill patterns and density



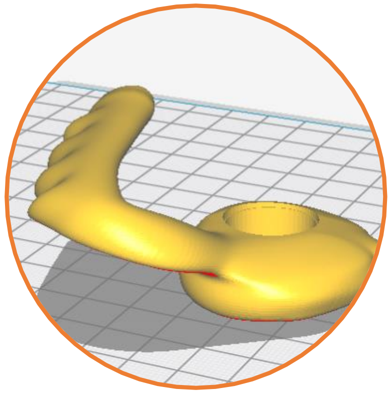


- Most important parameters to set in the slicing software
  - Hot end printing temperature, depends on the material
    - PLA: 190 – 220ºC; PTEG: 195 – 220ºC; ABS: 220 – 260ºC
    - Lets use PLA material and 205ºC
  - Layer Height
    - Low value improve quality but decreases speed
    - In general each layer with 0.2 mm is a good compromise between speed and quality
    - Lets use 0.2 mm
  - Infill
    - To improve print quality, reduce printing time and waste of material the interior of the part is filled with a pattern. Only the wall, bottom and upper becomes solid.
    - Most of the mechanical resistance of a part to bending is obtained from the walls. So, infill density does not have a significant impact in the structural resistance if is more than 20%.
    - We will use 20% and a rectangular pattern

- Positioning properly the part for printing is one of the most important tasks.
  - It allows a proper adhesion to the bed, by increasing contact area
  - If well positioned the number of supports to print regions in balance will decrease, as it will be seen latter



Position as came from CAD



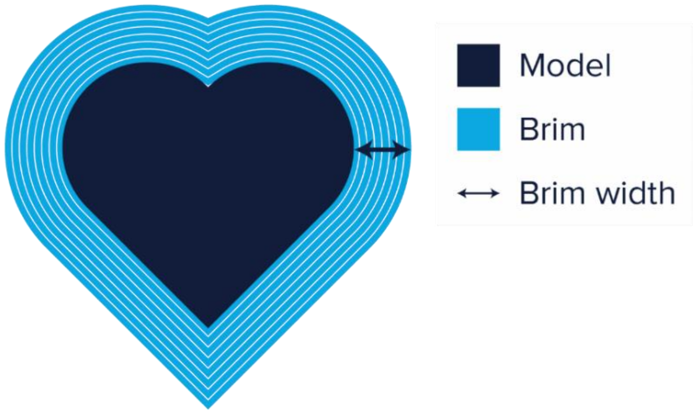
Better position for 3D Printing

- If the part separates from the building plate while it is printing you will lose that work. Several techniques are available to improve adhesion.
  - Have a printer with hot bed
    - For PLA set the bed temperature between 40ºC and 60º
  - If your printer does not have a hot bed
    - Use a Lac that is sold in 3D printing stores
- Other techniques are recommended to improve build plate adhesion as follows in next slide.

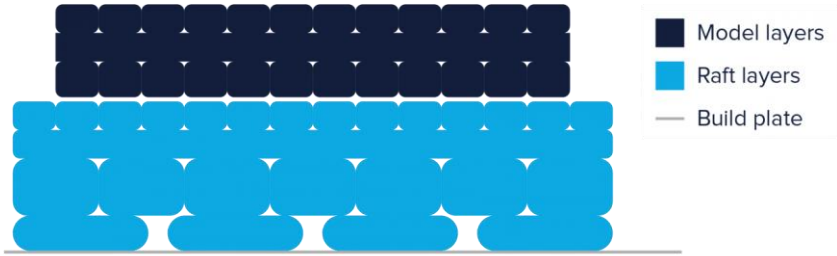
Top View of the First Layer

Skirt - Is a line printed around the object on the first layer, but not connected to the object. This helps priming the extrusion and can also be a good check for bed leveling before the print starts

Brim – Is a single layer flat area around the base of the model to prevent warping and to increase the contact area with the part

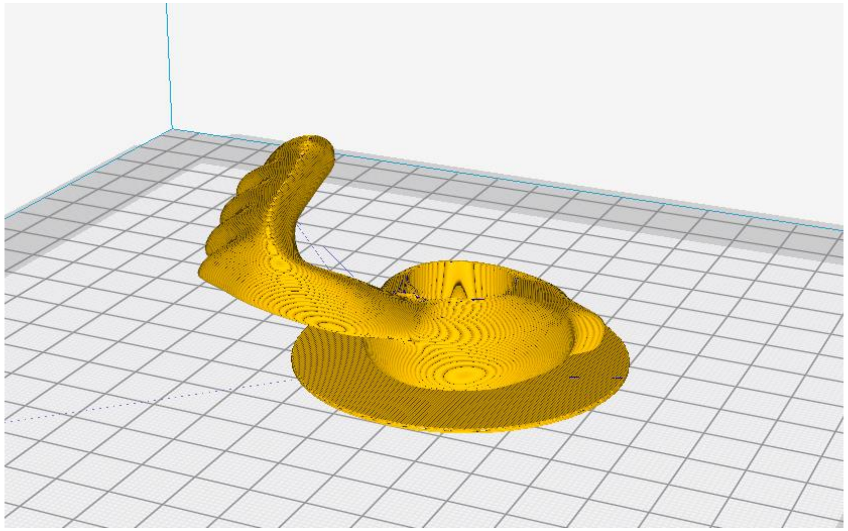


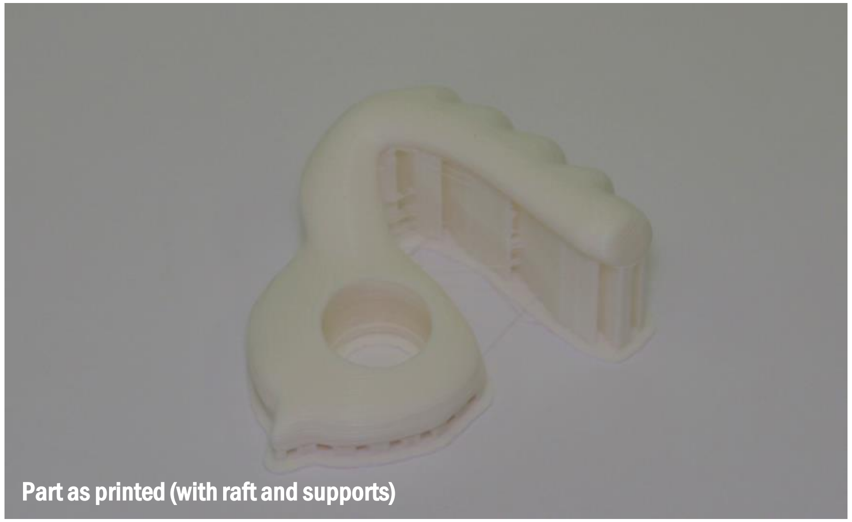
Raft - Adds a thick grid with a roof between the model and the build plate. This is particularly useful for parts that are no flat.



Side View

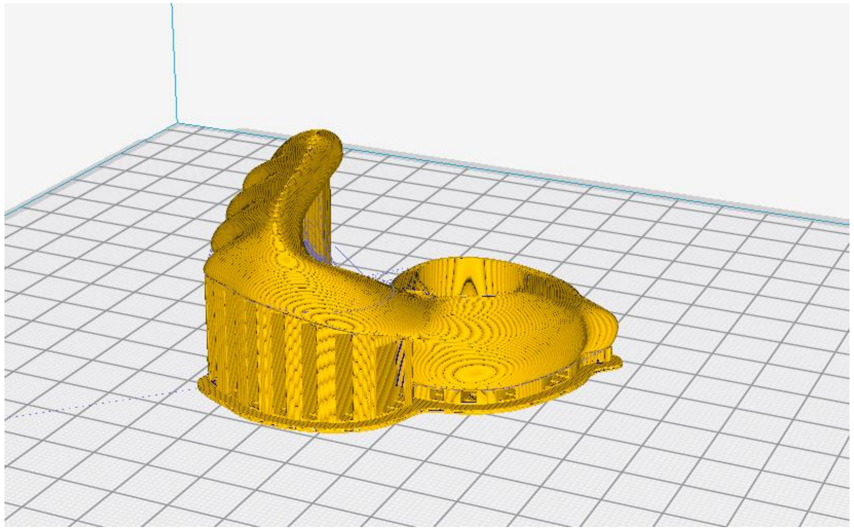
As this part has a very low contact area with the bed it will be created a raft as shown.





Part as printed (with raft and supports)

Many parts require supports to be properly printed. If not those regions in balance will drop on the bed. Supports are like towers, to support some regions of your part. The supports can be broken after printing the part.



Part after some finishing

Traditional Techniques
Knowing the past to improve in the future

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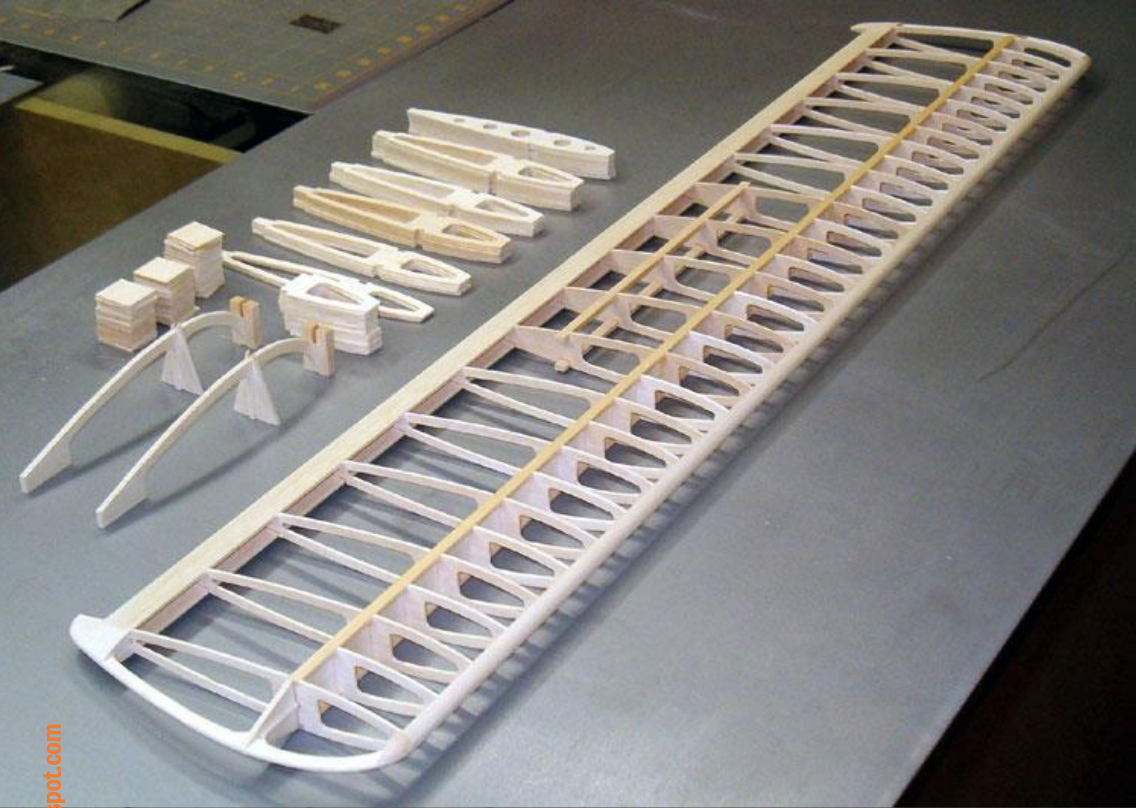

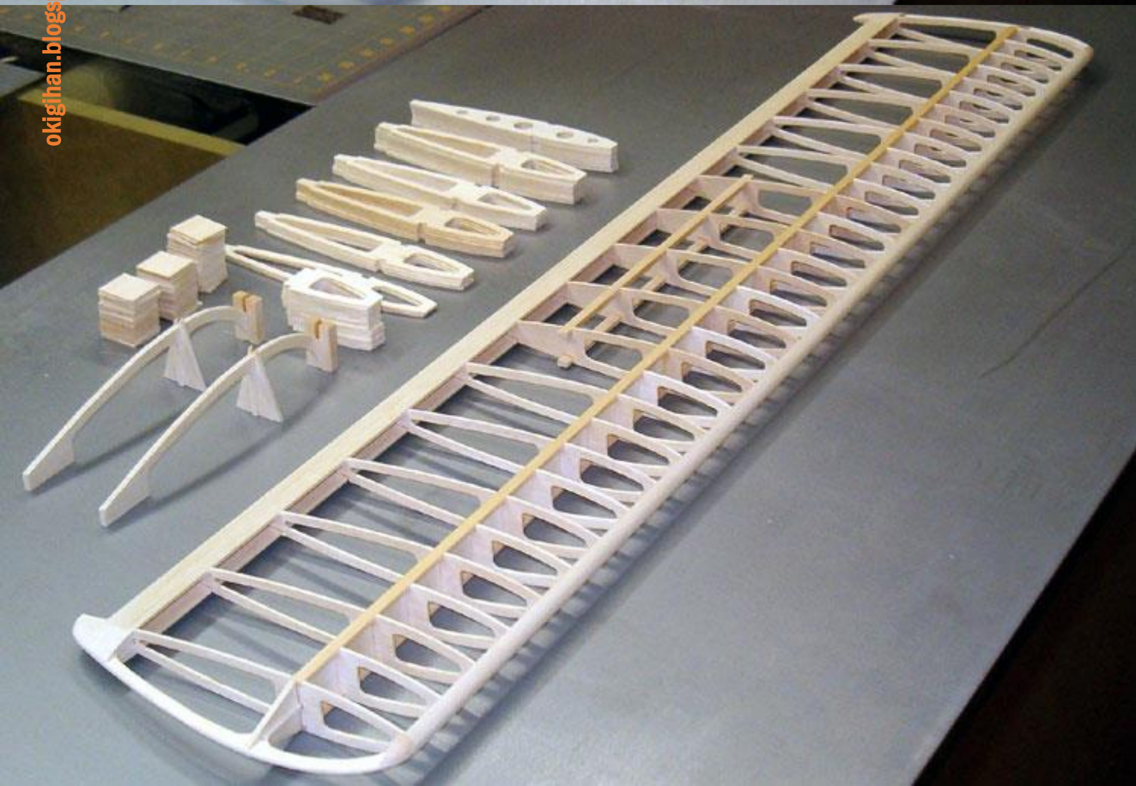

Historically, most of the aircrafts models were built with balsa wood. The models follow in general the structure of those real aircrafts, becoming quite light and efficient. Balsa is very light and can be easily worked and bounded.

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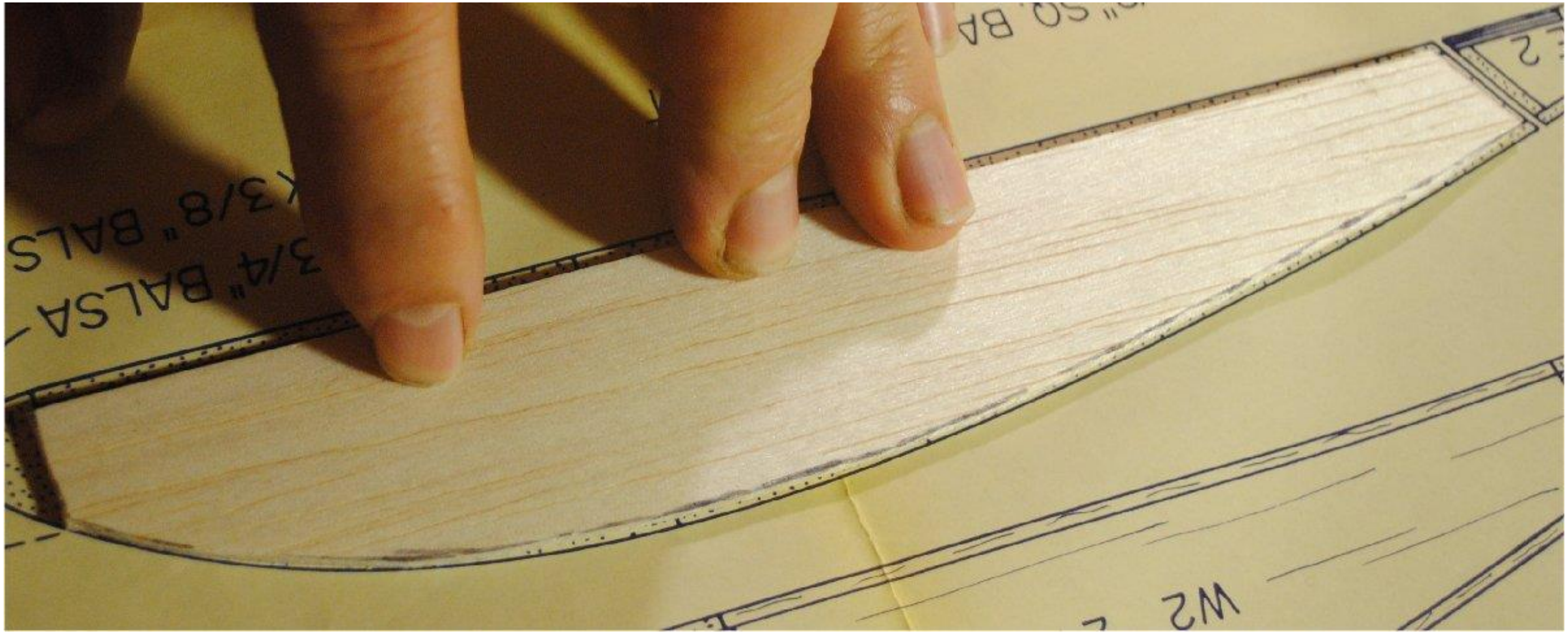
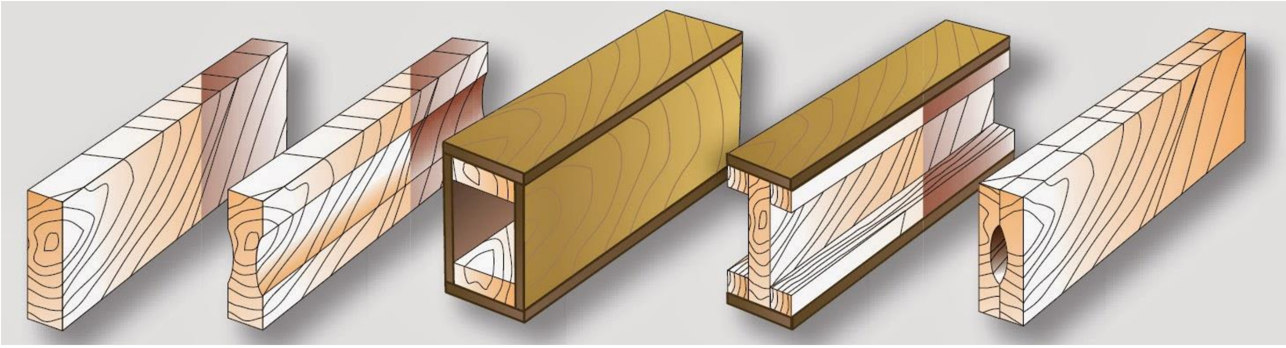
Cutting and finishing a balsa wood wing rib with a mould

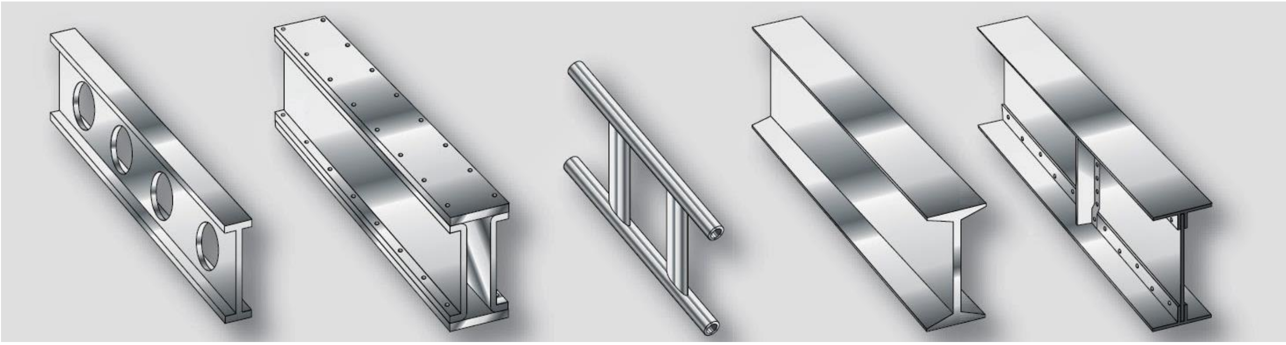


The spar is the most important structural part of a wing. It will transmit the aerodynamic forces to the fuselage of the aircraft. Next figure presents some examples of spars designs.

Wooden wing spar cross-sections



Metal wing spar shapes



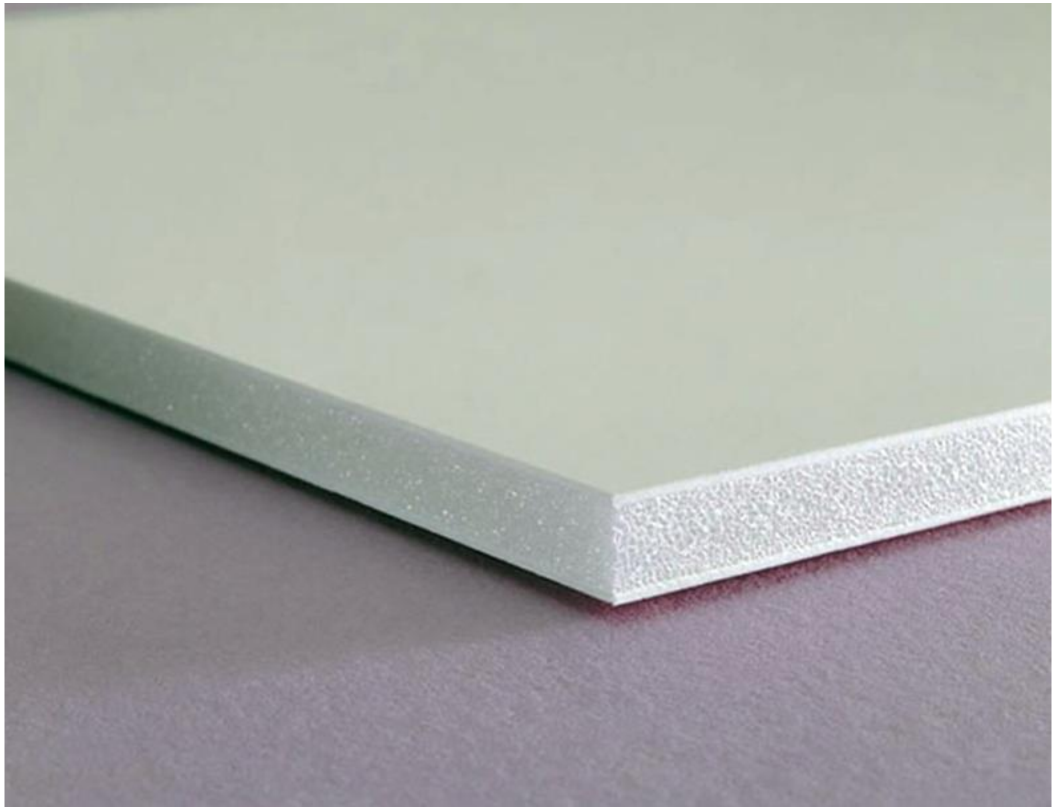
okigihan.blogspot.com

http://www.houseoffrog.co.uk/gliders.htm

- Balsa wood is still and excellent material for models. However it can be difficult to find in non-specialised stores, and in general it is more expensive than foamcore

- Foamcore is a composite material, made with two layers of cardboard and a polyurethane core, which is quite often used in school works or in the office. It can be easily found in a stationary store

- In some cases, foamcore can be lighter and stronger, compared with balsa wood, specially if is used in large panels



Good job!

Fly to Module #5

Module #1

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