Printing the Serpent

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A guide to downloading, 3D printing and assembling the Bate Collection Anon
Serpent model.

www.bate.ox.ac.uk

November 2016

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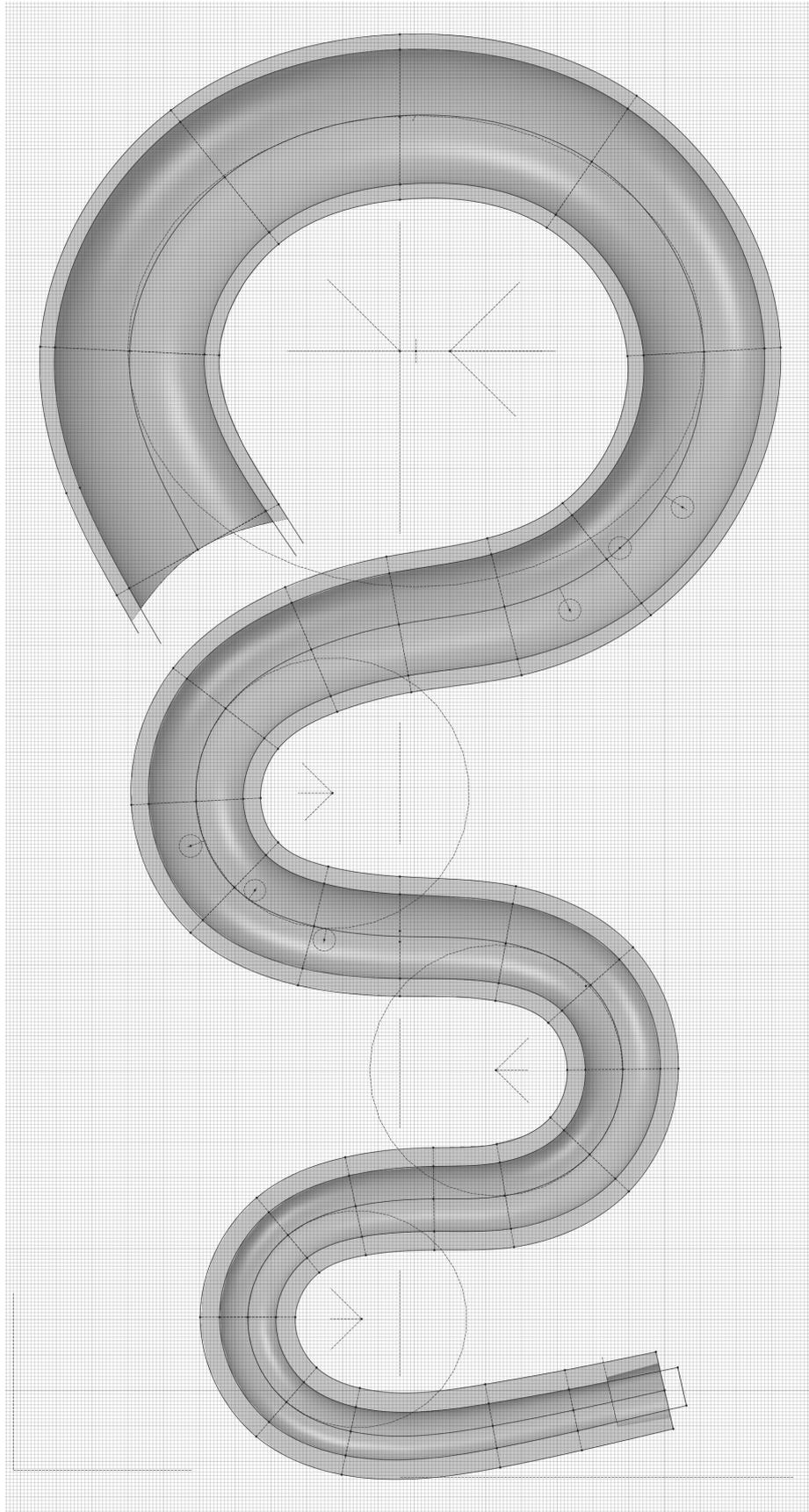
Figure 1: Geometry of the Bate Serpent

Introduction

The serpent is a wood bass horn with a characteristic curved shape and six finger holes for playing. Although they look like something out of the dark ages, they were invented in 1590 by Canon Edmé Guillaume of Auxerre and were used for many centuries to accompany sung liturgy in French churches. When played softly the serpent complements the human voice extremely well. When played more loudly the serpent provides a solid bass line and they were introduced into military bands from about the 1750s onwards being used extensively throughout Europe and in the USA until the 1830s.

Serpents are one of the most easily recognised and memorable musical instruments in any historic collection, and most collections will hold several examples, the Bate Collection has a dozen in various forms (some are shown in Figure 2). However, the serpent does not fit well into the modern orchestra and these instruments fell into disuse and languished in obscurity, unloved, for more than a hundred years until the early music revival of the 1970s. There is now a surprisingly active body of serpent players and enthusiasts[1] and a good choice of playable replica instruments are available, at a price.

Due to its sinuous shape and complex form the Serpent is perhaps ideal for 3D printing technology. This 3D printed instrument described here is modelled on an example of a French church serpent produced by an unknown craftsman and which was very probably made in the early 19th century. It is currently held in the Bate Collection in Oxford (inventory #500). The original instrument was modelled using *RS DesignSpark Mechanical*, a free to use CAD (Computer Aided Design)[2] package to create the printable object.

The body of the prototype instrument was printed in 20 sections on an Ultimaker2 3D printer at the Imperial College Advanced Hackspace (*http://icah.org.uk)* and the parts assembled by gluing. The mouthpiece and bocal (mouthpipe) add an extra six parts.

b, c, d – courtesy of the Bate Collection, Oxford

Figure 2: Church and Military Serpents

[1] See the Serpent Website, for instance: *www.serpentwebsite.com*
[2] https://www.rs-online.com/designspark/mechanical-software

3D printing in PLA material takes over 200 hours and the finished serpent weighs about 2Kg. This full-sized (approx 800mm tall) 3D printed musical instrument looks similar to the original (Figure 3), sounds well and plays very authentically - that is, it's just as difficult to play as the real thing. A half-size black and yellow striped "serpenteau" was also 3D printed - taking only 50 hours, then glued and assembled as with the full size instrument.

Figure 3: 3D-printed serpent and 19th Century original

It should be pointed out that there is nothing about the serpent - design, making or playing - that is for the fainthearted or the easily distracted[3]. The 3D-printed version, while not calling on traditional woodworking craft skills, still requires a significant investment in time, care and attention to complete. However, assuming you have access to a suitable 3D printer, then the materials cost is low compared to a purchased instrument - around £60 for the printer filament - and only a few simple hand tools and some consumables (varnish and adhesive or plastic solvent) are required to complete the full sized instrument[4].

Before starting it is essential that you familiarise yourself with your 3D printer and the "slicer" application that you intend to use.

Quality of 3D printing is essential for all wind instruments, and there must be no air leaks, unintended holes or delamination between printed layers. A thicker than normal surface skin (1.2mm) and infill percentage (30%) than usual is strongly recommended to assist with air-tightness, rigidity and playing weight of the final instrument.

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[3] And possibly even for the entirely sane.
[4] Take particular care when using handtools - obviously - and wear suitable eye-protection; use solvents and adhesives responsibly in a well-ventilated area. Always under adult supervision.

All the design files you will require can be downloaded and used for personal use for free. Before starting you should download them all (26 in total) and confirm that they will be suitable for your slicer program and printer combination (for instance, Cura and an Ultimaker 3D printer). The parts are all designed to fit easily within a 200x200x200mm 3D print volume, though check with Table 1, columns **G**, **H** and **I** for detailed dimension requirements.

Equipment and materials

To complete the full sized serpent you will need:

Resources:
> The 26 .stl design files (download)
> Access to a 3D Printer (min 140mmW x 105mmD x 160mmH) for an
>   extended period

Various hand-tools:
> modelling knife,
> plumber's pipe deburring tool (optional),
> emery ("wet and dry") abrasive paper, medium to fine
> miscellaneous flat and curved needle files (miniature "diamond" types work
>   well)
> drill bits (3mm, 2mm) and holder
> miscellaneous small paint brushes

Materials:
> Two 1Kg reels of PLA material (plus some extra for reprinting failures and
>   mistakes, they happen!)
> Sanding sealer primer (brushable), <250ml.
> Plastic Weld solvent (or other suitable adhesive)

Download the printer (.stl) files

Locate and download to your computer the 26 3D printer (.stl format) files. The main body of the serpent is available as 20 individual files ("Bate anon serpent part 01.stl", the bell end, to "Bate anon serpent part20.stl", the mouth end). Figure 4 shows the general shape and relationships between these parts. Note that they have been pre-rotated to fit directly onto the 3D printer bed.
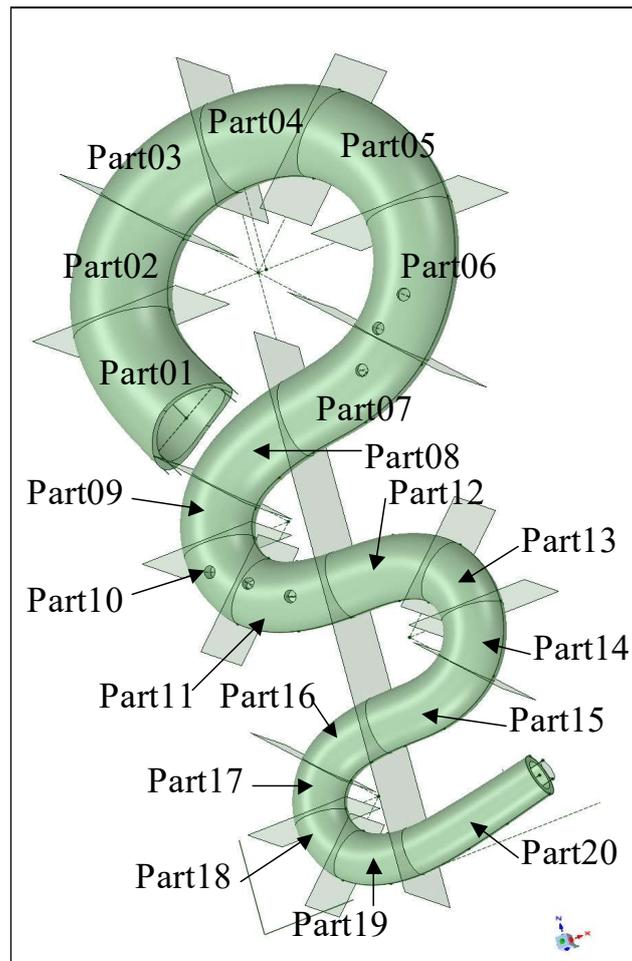
Figure 4: Serpent main body parts and their relationships

Printing the Serpent

Using the slicing (stl to gcode converter) application (e.g. "Cura" for the Ultimaker series) that came with your 3D printer prepare printer files for each component part. If necessary, convert each of the 20 parts and preserve your naming convention (to "gcode" files for Cura).

To allow each component part to be built upwards from the printer bed, most, though not all, have been rotated by 90º, -90º or 180º in the up-down (Z) printer axis so that the relevant horizontal and vertical cut lines lie flat on the printer bed. These rotation values are shown in column **B** of Table 1. A negative value indicates a counter-clockwise rotation for the part as designed relative to the printer baseplate.

Using the print settings described below a full sized serpent will take a very long time to 3D print (over 200 hours in total) using PPP technology. Table 1, column **C**, summarises the estimated time it will take to print each component part of the full size serpent. These figures assume a print layer thickness of 0.2mm (double the typical 0.1mm layer thickness), a print wall thickness of 1.2mm (three layers), 50mm per second print head speed, and 30% inner fill. If you change these values the print time may change dramatically – doubling, for example, if a 0.1mm print layer thickness is chosen, about 25% longer overall for a print wall thickness of 1.6mm.

Print each part individually or in small groups in the colour(s) of your choice, ready for assembly. Check for failed or sub-standard prints and discard. An element of organisation and perseverance is required to complete all parts of the print successfully. It is strongly recommended that you label and number each part as soon as it is printed to aid assembly, Figure 5.

Print the four parts of the bocal and the two parts of the mouthpiece in a matching or contrasting colour material.

Figure 5: 3D printed Serpent parts prior to assembly

Print step summary:

- Choose 3D print settings to estimate achievable overall print times and quality
- Convert (slice to gcode) each component part using the slicing application supplied with your 3D printer
- 3D print each component and check for print quality
- Print the bocal (mouthpipe) and mouthpiece parts

Assembling and finishing the serpent print

You should now have 20 separate 3D prints of the serpent body. Label and check them against the drawing and against each other in order to confirm that they are a complete set and they all fit together as they should.

The inner burrs that appear where the part attached to the printer bed can be removed with a plumber's pipe deburring tool or rounded file and smoothed as required. The outer burr can be filed and then trimmed away. There should be no ridge on the inside or outside surfaces when placed together.

The two alignment holes on each adjoining flat surface should be opened up with a 3 mm drill to ensure a short length of 3 mm diameter printer filament material will sit in each comfortably (with a 1.8 or 2 mm drill and 1.75 mm filament material for the worm). Make sure the length of filament used does not hold the adjacent parts apart and that all surface burrs from the drilling are removed prior to assembly.

If there is any possibility of air leak or diffusion through the finished wall of the serpent you should seal the inside surface of every piece before assembly by brush coating it with a suitable finishing sealant material. The prototype is internally coated with three brushed applications of solvent based "sanding sealer". This both fills

small pinhole gaps in the surface and gives the inner surface a nearly smooth, somewhat glassy appearance. This is highly recommended at this stage, to improve sound quality - and as there is little possibility of remedial action on the internal surface once the instrument is assembled.

The top and bottom surface of each component should be made flat and smooth by finishing with a file (smaller parts) or medium grade emery paper for the larger diameter parts. Most effective is to place the emery paper on a flat surface and rub the flat surface of the part with a circular motion using moderate pressure over the emery surface. Continue until all the print ridges have been removed and the end surfaces of the part are smooth and lightly abraded.

In no particular assembly order, each part must be joined to its neighbour by gluing. Place short lengths of filament material into the matching holes and check (and double check) that the two adjacent parts both match and fit closely – look for any light through the join when they are held together. If so, cut, sand or file down any raised points and carefully clear away any plastic shavings or swarf.

As no two parts are the same, always check that there is no discontinuity or ridge between the two parts to be assembled. Remember that while most parts follow a natural inner curve some parts curve away from each other. The alignment pins offer no guidance in this respect[5]. Keep a diagram of the complete instrument to hand and keep checking; once glued it's too late to change.

The parts can be permanently fixed together with Plastic Weld (Methyl dichloride) solvent, with UHU glue or other adhesive. When ready to make the join brush each surface with Plastic Weld. Two coats applied in quick succession to each surface appears to work well, before pressing together firmly and holding for a short while until the joint hardens. Equally, the adhesive can be applied to the surfaces before joining – follow the instructions (and handling precautions) on the packet.

If small gaps appear along the seam formed, a small quantity of Plastic Weld can be brushed into the gap, which will spread by capillary action to close the gap. Slightly larger gaps can be closed by carefully filing around the join with a small elliptical modelling file to a depth of about one millimetre and brushing solvent into the ridge formed. The filing action forces powdered material into the gap, which is melted as a filler by the solvent.

The four parts of the bocal are prepared and assembled in a similar manner. Print, assemble and complete the mouthpiece. Once completely assembled the full size serpent appears quite rigid and of a good weight (1,860 gms[6]).

Assembly step summary:

- ❑ Remove the burrs around the print base and open up the alignment holes
- ❑ Seal the interior surface to make airtight

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[5] The alignment pins could, of course, have been variously offset and then there would be no ambiguity.
[6] Rather less than the estimate from Cura shown in **Error! Reference source not found.**. The actual print times were generally shorter than the Cura estimates as well.

- □ File or sand (emery paper) the top and bottom surfaces of the parts
- □ Insert alignment pegs between parts and (double) check shape
- □ Use solvent or glue to attach all the parts together
- □ Fill any gaps between parts
- □ Assemble the bocal and mouthpiece

Printing a baby serpent (serpenteau or worm)

Given the length of time and amount of material required to complete a full size serpent print you might consider making a half-size replica to check that the geometry of the design is sound and to get practice at assembling and finishing the instrument. At the printer settings recommended above, the overall print time is reduced to about 50 hours. Easy. Note that the mouthpieces printed at half-size are very thin at the shank end and some redesign specific to the half-size model might be considered.

The serpenteau, or tenor serpent, is regarded by some as suitable for children as a learning aid or for those with a limited finger span. The serpenteau is rather more flexible than the full size 3D printed instrument, it plays, but is probably not strong enough to be handled with any gusto.

The procedure is similar to that for the full size print, each part must be loaded into the slicing application and rotated, but also reduced in size by 50% (x0.5). It is now possible to layout half the component parts onto a 200x200mm 3D print table for simultaneous printing. Figure 6 (left) shows a printer table layout for the even numbered parts, Figure 6 (right) the odd numbered parts of the serpenteau. Figure 7 shows the 3D prints, in black and yellow, before and after assembly – giving a slightly venomous and rather waspish appearance to the finished item.
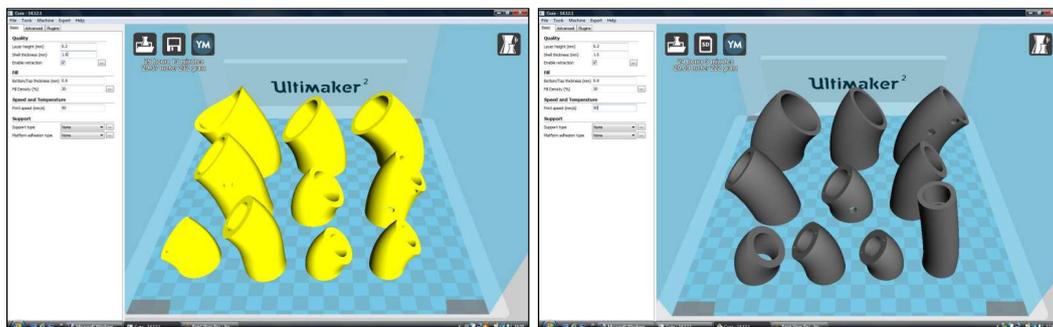

Figure 6: Alternate yellow/black serpenteau components on the print table (Cura screenshots)
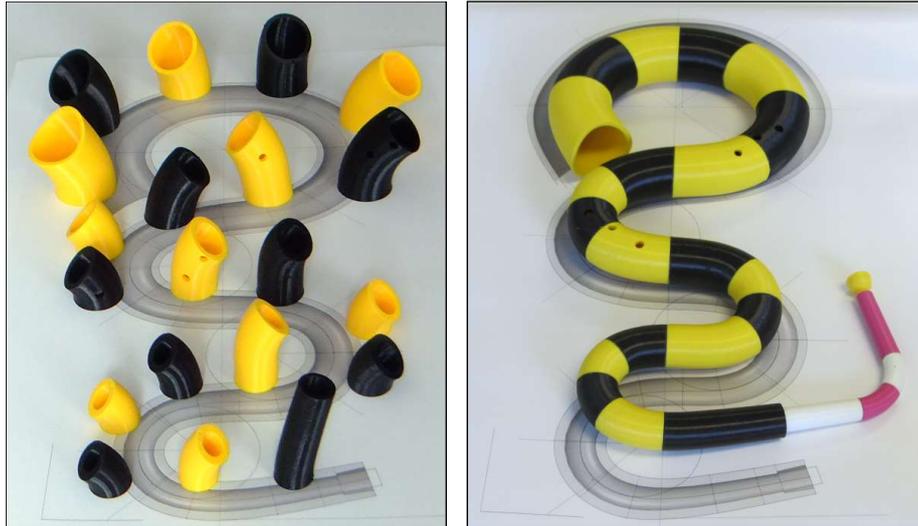
Figure 7: The serpenteau before and after assembly

Assembly and finishing of the serpenteau are as for the full size serpent.

file	rotation	hours	metre*	gram	Cost	W mm	D mm	H mm	file(Mb)	start
Bate Anon Serpent (#500) stl print files - full size										
file	rotation	hours	metre*	gram	Cost	W mm	D mm	H mm	file(Mb)	start
Bate anon serpent part01.stl	180	18.38	25.32	200	6	139	104	153	2.1	
Bate anon serpent part02.stl	0	16.75	22.73	180	5.4	138	101	133	3.2	
Bate anon serpent part03.stl	90	14.48	20	158	4.75	115	97	133	1.9	
Bate anon serpent part04.stl	-90	17.4	24.04	190	5.71	115	94	155	2.7	
Bate anon serpent part05.stl	0	14.35	19.58	155	4.65	122	90	127	2.5	
Bate anon serpent part06.stl	180	13.83	18.7	148	4.44	111	86	132	3.1	
Bate anon serpent part07.stl	-90	16.73	22.97	182	5.45	119	81	160	2.7	
Bate anon serpent part08.stl	90	11.92	16.14	128	3.83	107	78	119	2.3	
Bate anon serpent part09.stl	0	6.97	9.38	74	2.23	85	75	81	2.1	
Bate anon serpent part10.stl	180	6.82	9.12	72	2.17	84	73	79	3.3	
Bate anon serpent part11.stl	90	10.18	13.81	109	3.28	86	71	117	2.5	
Bate anon serpent part12.stl	-90	10.7	14.77	117	3.5	82	68	127	2.6	
Bate anon serpent part13.stl	0	5.55	7.51	59	1.78	75	64	73	2.9	
Bate anon serpent part14.stl	180	5.4	7.25	57	1.72	74	63	72	2.7	
Bate anon serpent part15.stl	-90	9.48	13.12	104	3.11	74	61	125	2.8	
Bate anon serpent part16.stl	90	6.08	8.25	65	1.96	71	58	86	2.4	
Bate anon serpent part17.stl	0	4.15	5.7	45	1.35	66	55	64	2.7	
Bate anon serpent part18.stl	180	4.2	5.52	44	1.31	64	54	63	2.5	
Bate anon serpent part19.stl	90	5.2	7.3	58	1.73	65	52	85	2.8	
Bate anon serpent part20.stl	-90	9.37	13.14	104	3.12	72	49	153	0.94	
		207.94	284.35	2249	67.49					
Bate anon serpent bocal01.stl	180	4.33	5.53	44	1.31	32	32	131	0.317	
Bate anon serpent bocal02.stl	0	2.01	2.41	19	0.57	46	30	60	8.45	
Bate anon serpent bocal03.stl	90	1.87	2.29	18	0.54	42	28	60	8.2	
Bate anon serpent bocal04.stl	-90	3.01	3.88	31	0.92	27	27	110		
		11.22	14.11	112	3.34					
Serpent bell mouthpiece01.stl	180	0.82	1.04	8	0.25	37	37	25		
Serpent bell mouthpiece02.stl	0	0.33	0.35	3	0.08	21	21	31		
		1.15	1.39	11	0.33					
Ultimaker 2										
0.2mm layer										
1.2 shell wall thickness										
30% fill density										
50mm/s print speed										
*Assumes 3mm filament, 0.4mm nozzle										

Table 1: Serpent download files, times, materials and dimensions