LAPIN AMK
Lapland University of Applied Sciences

Modification and repair of an FLSUN QQ-S pro 3D-printer for utilization at the university laboratory

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Abstract of Thesis

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This thesis aims to present the FLSUN QQ-S pro delta 3D printer, its capabilities and limits. To achieve that a used model is obtained repaired and modified. The goal is to improve the printer and prepare it for the application in the laboratory of the university.

For readers unfamiliar with the definition of additive manufacturing, the thesis starts with a theoretical part, explaining the necessary basics. 3D printing, FDM printing and the affiliated machines are summed up as well.

Firstly, the configuration of the FLSUN QQ-S pro printer was examined and documented. Its components and basic capabilities were explained.

Secondly, the 3D printer was repaired to restore its basic functionality and get the already applied modifications to work properly. At this stage the printer is tested to have a comparison base.

Thirdly, possible modifications for the printer were explored and their potential to improve the printer evaluated. Some of the introduced modifications were then applied to the printer.

Finally, the new configuration of the printer was tested and the results compared to the capabilities of the old setup. The improvements were described and an outlook about potential further modifications given.

Key words	Additive manufacturing, 3D printing, Delta printer, FLSUN QQ-S pro
Other information	The thesis includes a folder of additional material

CONTENTS

FOREWORD

Special thanks to Antti Niemelä for donating the FLSUN printer for the project, investing in the parts needed for modifications and providing some guidance and ideas during the process. Without him the project would not have been realized.

The Thingiverse community and its contributing members as well as other makers, who share their ideas online provided a lot of ideas and solutions to the project. Hereby grateful acknowledgement to their work.

SYMBOLS AND ABBREVIATIONS

3D	Three dimensional
ABS	Acrylonitrile butadiene styrene
AIO	All in one
CAD	Computer aided design
CNC	Computerized numerical control
FDM	Fused deposition modelling
FFF	Fused filament fabrication
ISO	International standardization organization
PA	Polyamide
PEI	Polyethyleneimine
PETG	Polyethylene terephthalate glycol
PLA	Polylactic acid
PTFE	Polytetrafluoroethylene
TPE	Thermoplastic elastomer
TPU	Thermoplastic polyurethane

1 INTRODUCTION

Additive manufacturing, also known as 3D printing, is a rapidly growing technology that has revolutionized the manufacturing industry. Unlike traditional manufacturing techniques that involve subtracting material from a block of material to obtain the desired shape, additive manufacturing builds objects layer by layer using computer-aided design (CAD) software. This process has enabled the creation of complex shapes that were previously impossible to manufacture using traditional methods.

Additive manufacturing has gained popularity in various industries, including aerospace, automotive, medical, and consumer products. The technology's versatility, flexibility, and ability to produce customized products on demand have made it an attractive option for companies seeking to reduce production costs, speed up the production process, and provide tailored solutions to their customers.

A popular and affordable 3D printer in the market today is the FLSUN QQ-S pro. This printer uses fused deposition modelling (FDM) technology to create objects layer by layer, using a range of thermoplastic materials such as PLA, ABS, and PETG. The FLSUN QQ-S pro offers a large build volume, precise printing, and is easy to assemble, making it an attractive option for hobbyists, educators, and small businesses.

This bachelor thesis aims to explore the capabilities of the FLSUN QQ-S pro 3D printer, including its technical specifications, software compatibility, and print quality. The thesis will investigate the various applications of the FLSUN QQ-S pro in fields such as education, prototyping, and small-scale manufacturing. Additionally, the thesis will examine the advantages and limitations of the FLSUN QQ-S pro compared to other 3D printers on the market.

Overall, this thesis will provide a comprehensive analysis of the FLSUN QQ-S pro 3D printer, highlighting its potential to enable innovation and creativity in various industries, as well as its impact on the 3D printing market.

2 KNOWLEDGE BASE

2.1 Additive manufacturing

Additive manufacturing (AM) is a production technique that has been developed and applied approximately since 1985. The main difference to conventional manufacturing techniques is that material is added step by step instead of subtracting material from bigger blank parts. The deposition of material happens mostly layer by layer to create the final part in the end. (Godec, Gonzalez-Gutierrez, Nordin, Pei, & Ureña Alcázar 2022, 1.)

This principle enables the generation of complex structures and geometries that would not be manufacturable with conventional methods. Also, the parts can usually be directly created from computer aided design (CAD) models, without the need for deriving drawings first. (Godec et. al. 2022, 1.)

Additive manufacturing can be classified into different groups according to the phase of the used material and utilized binding procedures as shown in Figure 1. This is also the accepted standard of the International Standardization Organization (ISO). All additive manufacturing processes can be associated to one of the seven categories. (Godec et. al. 2022, 6–7.)

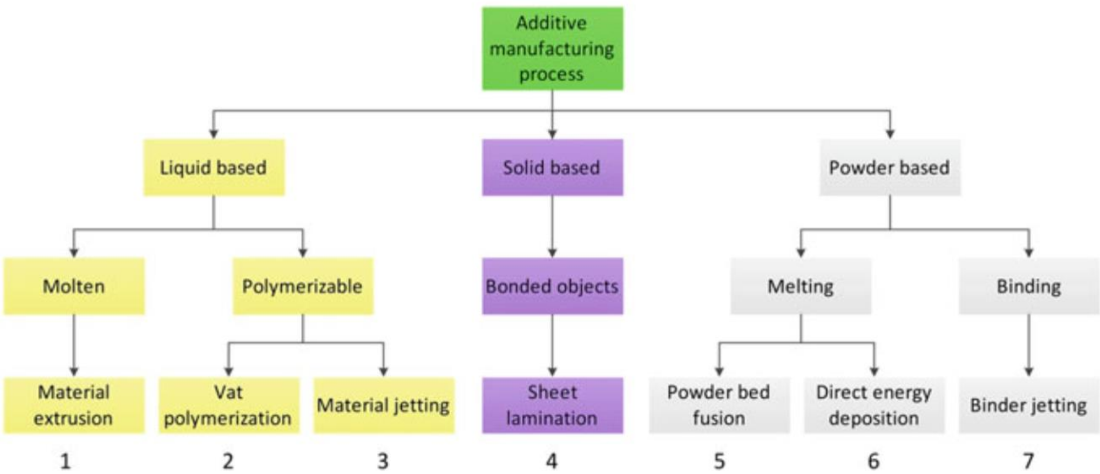

Figure 1. Classification of additive manufacturing according to ISO/ASTM 52,900 (ISO/ASTM) (Godec et. al. 2022, 6)

The market demands for additive manufacturing methods are increasing nowadays. Many manufacturers tend to offer their customers personalized or even individual solutions instead of relying on mass production of standard items. (Godec et. al. 2022, 1.)

Furthermore, additive manufacturing can reduce manufacturing time for prototypes as shown in Figure 2 due to its flexibility and lack of need to prepare workflows or design tools for the manufacturing process. Therefore, it is often referred to as rapid prototyping as well. (Godec et. al. 2022, 2.)

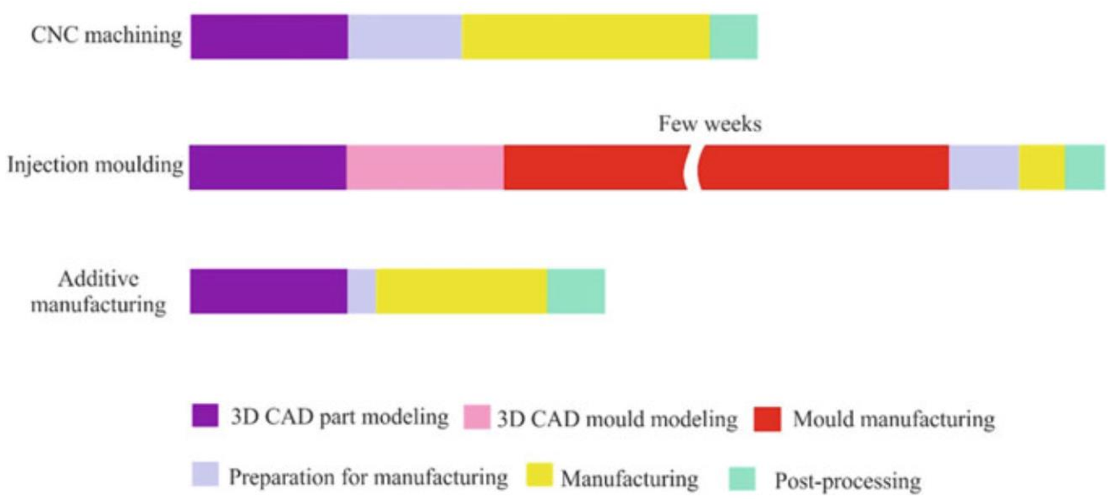

Figure 2. Comparison of production time between classic processing (CNC milling) and AM (PolyJet process) (Godec et. al. 2022, 2)

2.2 3D printing

3D printing is a malleable phrase, as it clearly refers to techniques of additive manufacturing but splits opinions on what concepts are included by the expression. Mostly the wording is used to describe all kinds of additive manufacturing except sheet lamination as mentioned in Figure 1.

As specified by the source, 3D printing is an additive manufacturing process in which a substrate is placed on a printing bed and then sprayed with binder using a movable nozzle. Layer by layer the bed is lowered and the process cycled through again. (Godec et. al. 2022, 17.)

This can be classified as binder jetting referring to Figure 1. According to the source this process is called 3D printing because of its similarity to inkjet printing. (Godec et. al. 2022, 17.)

In a more general sense, the expression 3D printing includes all manufacturing techniques, where a three-dimensional object is created automatically using an additive manufacturing machine, called the 3D printer. Those can generate the desired shapes from the code they are supplied with in a widely autonomous manner.

To achieve that, the CAD files containing the parts are loaded into a computer program called the slicer, which transforms them into a set of instructions, called the g-code, that can be understood by the 3D printer.

2.3 FDM printing

Material extrusion of filaments, also known as Fused Deposition Modeling (FDM) or Fused Filament Fabrication (FFF) is a common 3D printing technique. FFF is the most widely used material extrusion technique due to its simple and safe fabrication process, low equipment cost, and availability of a variety of filaments for printing. (Godec et. al. 2022, 36.)

The process involves extruding a filament through a nozzle and depositing it on a building platform layer by layer, where it solidifies. The technique used in FFF machines is a ram extruder that pushes the softened material out of the printing head. A scheme illustrating the process can be seen in Figure 3. The filament must be mechanically strong, have enough friction with the wheels, not buckle, and be flexible enough to be spooled for easy storage and feed into the liquefier. (Godec et. al. 2022, 36.)

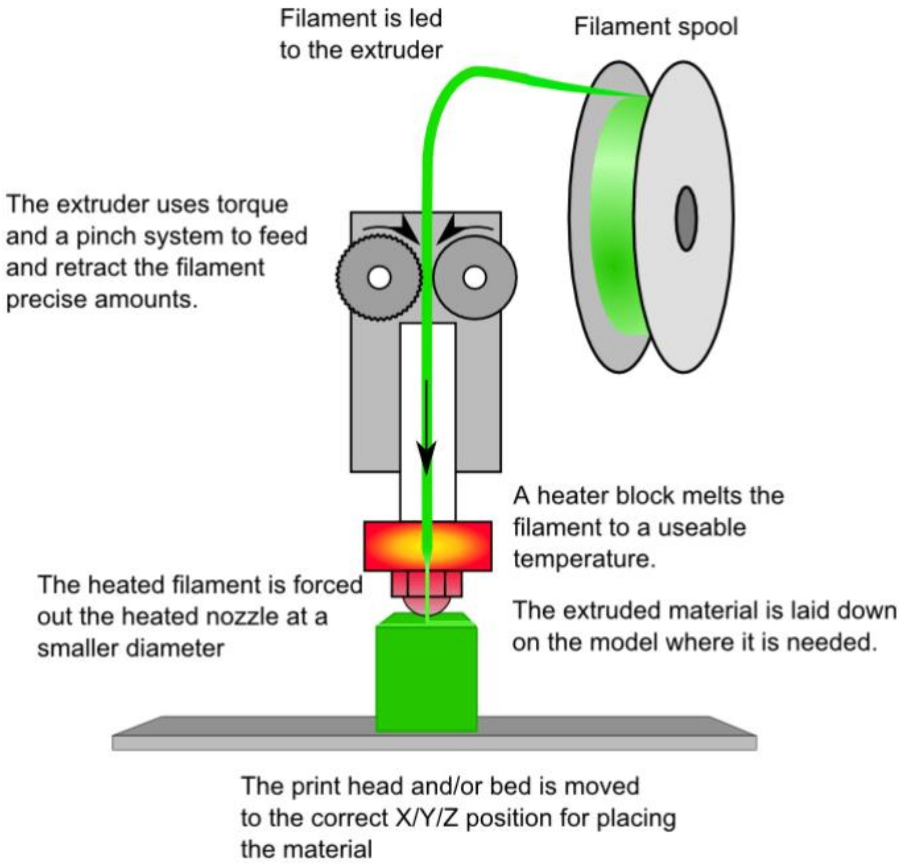

Figure 3. Illustration of FDM printing technology (3D Kywoo 2021)

Various thermoplastics-based materials, such as ABS, PLA, and PA, are commercially available as filaments for FFF. Additionally, there are composite materials and highly-filled polymeric materials available. (Godec et. al. 2022, 36–37.)

The FDM process was pioneered by Stratasys, but after the expiration of their patents, other companies have emerged as competitors in this market. The alternative terminology FFF was introduced before to avoid copyright issues and refer more clearly to the technology of filament based material extrusion. (Godec et. al. 2022, 35–37.)

2.4 FDM 3D printers

2.4.1 Cartesian and delta printers

A Delta 3D printer is a type of desktop 3D printer that differs from the more common Cartesian 3D printer in how it locates points in 3D space (Flynt 2020). While a Cartesian 3D printer moves the print head along the x, y, and z axes, a Delta 3D printer instead mounts the print head on three moving arms that push and pull to control its position, as shown in Figure 4. (Anderson 2023.)

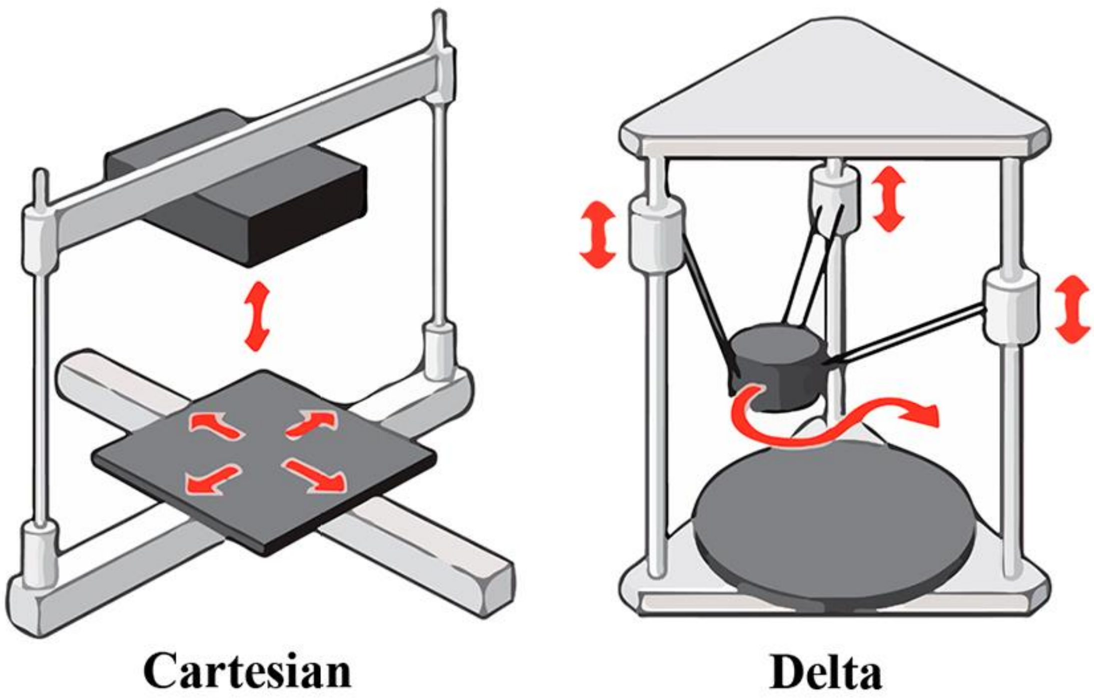

Figure 4. Schematic of cartesian and delta printers (Schmitt et. al. 2018, 884)

Delta 3D printers plot points along the Cartesian coordinate system, but the coordinates have to be translated to the specific angles that each of the three articulating arms need to be at. This translation is done via simple trigonometric functions. The three arms of a delta 3D printer give it its distinct triangular frame. (Flynt 2020.)

Delta 3D printers have a stationary circular print bed and are thin and long, making them suitable for printing tall and narrow models. However, they have a small circular base compared to most cartesian 3D printers, which means that it may be necessary to split models into separate parts. They are capable of printing at high speeds, with print speeds of up to 300mm/s not being unheard of. (Flynt 2020.)

Delta 3D printers exclusively use Bowden extruders, which helps to optimize the rapid movement of its three arms. However, this also introduces complications if one has to use a flexible filament like TPU or TPE. The extra room that the Bowden extruder creates between the extruding gears and the nozzle increases the chances of deformation of the filament, which can lead to extrusion problems or clogging of the nozzle. (Flynt 2020.)

In summary, delta 3D printers have several pros and cons. On the one hand, they are fast and suitable for tall models. On the other hand, they have a limited base size and may not work well with flexible filaments. If one is running a 3D printing business where quick turnover is valuable, then a Delta 3D printer would be a good choice. However, if one has no plans of building particularly tall and narrow models, or if they need to use flexible filaments, then a Delta 3D printer may not be the best investment. (Flynt 2020.)

2.4.2 Printer components

Effector cage:

The mounting structure for the hot end, which is connected to the frame and moved by the stepper motor using belts or threaded rods. If the printer uses direct drive, it is often called extruder, since the extruder then sits directly on top of the hot end.

Hot end:

An assembly of parts essential to every FDM printer, which has the job to melt the filament and contain the nozzle, heater block, heating cartridge, thermistor, heat break and heat sink. (Anderson 2023.)

Nozzle:

The metal part which deposits the molten material onto the print bed through a small hole, determining the surface quality of the print by the size of that hole. The nozzle is screwed into the heater block. (Anderson 2023.)

Heater block:

A metal part which distributes the heat from the heating cartridge to the heat break and nozzle, providing a hot section where the filament melts.

Heating cartridge:

A resistance heating element, that sits in the heater block and is connected to the mainboard. (Anderson 2023.)

Thermistor:

The sensor, that continuously checks the temperature of the hot end to ensure the desired temperature is maintained. It sits in the heater block and is connected to the mainboard. (Anderson 2023.)

Heat break:

A threaded metal tube which is screwed into the heater block on one side and the heat sink on the other, leaving an isolating air gap between them. It touches the nozzle in the heater block, to ensure a continuous flow of material.

Heat sink:

A ribbed metal part, that is cooled by a fan, dissipating the heat spreading through the heat break. It keeps the filament cool, preventing it from softening too early and maintaining its ability to push the soft material below. (Anderson 2023.)

Cooling fans:

Different sizes of radial and axial fans are used to cool the heat sink, the extruded material at the end of the nozzle and the electric components like main board, motor drivers and power supply. (Anderson 2023.)

Extruder:

A plastic or metal gearbox that pushes the filament towards the hot end. It contains either one hobbed and one idler gear or two hobbed ones, which grab the material. If both gears are biting the filament and driven actively the extruder features dual drive. The extruder is powered by a stepper motor. (Anderson 2023.)

PTFE tube:

A flexible plastic tube, which guides the filament from the extruder to the hot end. It is tightly enclosing the material to reduce wiggling and thereby transferring the pushing force to the hot end. It is also called Bowden tube. (Anderson 2023.)

Build plate:

The build plate or printing bed is the surface on which the first layer of the part is printed. It is often heated to ensure the part is sticking to the plate and prevent any movement. It can be made from glass, plastic or metal and is often coated. (Anderson 2023.)

Frame:

Mostly made from metal and plastic parts, it is providing a mounting structure for the other components. It is required to be as stiff as possible in order to reduce the spreading of vibrations caused by the moving parts of the printer. (Anderson 2023.)

Rods and rails:

Metal parts which provide guidance to the moving parts of the printer. They are part of the frame.

Bearings and bushings:

Metal or plastic parts which slide on the rods and rails to move the hot end or print bed in relation to the other parts while reducing friction to a minimum.

Threaded rods:

Metal parts that spin in relation to a threaded bushing in order to transfer a moving force. They are driven by stepper motors and connected to the frame, hot end or build plate. (Anderson 2023.)

Belts:

Rubber parts that grab onto gears to transfer a moving force. They are driven by stepper motors and connected to the frame, hot end or build plate. (Anderson 2023.)

Enclosure:

A closed environment around the printer or its printing area, which can be heated and keeps dust out. It can be connected to the frame or be a separate part. (Anderson 2023.)

Stepper motors:

Electric motors that can be turned precisely by a minimum step of degrees to control the movement of the frame, hot end or build plate. They are connected to the stepper drivers. (Anderson 2023.)

Stepper drivers:

The electric controllers, which drive the stepper motors. Their quality determines the possible resolution of the print depending on their minimal step size. They are connected to the main board. (Anderson 2023.)

Mainboard:

The computation unit of the printer, where the g-code is interpreted and translated to electric signals, which control the electromechanical components of the printer. (Anderson 2023.)

Power supply:

A converter which supplies a DC voltage to power the main board and the electromechanical components of the printer. (Anderson 2023.)

Display:

The display shows the status of the printer and provides an interface to communicate with it. (Anderson 2023.)

Leveling switch:

A mechanical or optical switch that checks different points on the print bed and thereby determines its precise location and required offset. The accumulated data is then saved on the mainboard. (Anderson 2023.)

End stops:

Mechanical or optical switches that provide the stepper motors from moving the components too far, which could cause damages to them. (Anderson 2023.)

Filament sensor:

A mechanical or optical switch which recognizes the presence of filament and sends a stop signal if it runs out. Therefore, the print can be continued as soon as new material is provided.

3 PRINTER CONFIGURATION

3.1 FLSUN QQ-S pro

The FLSUN QQ-S pro delta 3D printer is a desktop 3D printer that uses a delta-style architecture. It features a triangular base with three arms that move the print head up and down along the Z-axis, the print bed does not move.

Speeds of 60mm/s or even 100mm/s should be possible with decent print quality. (FLSUN 2023.)

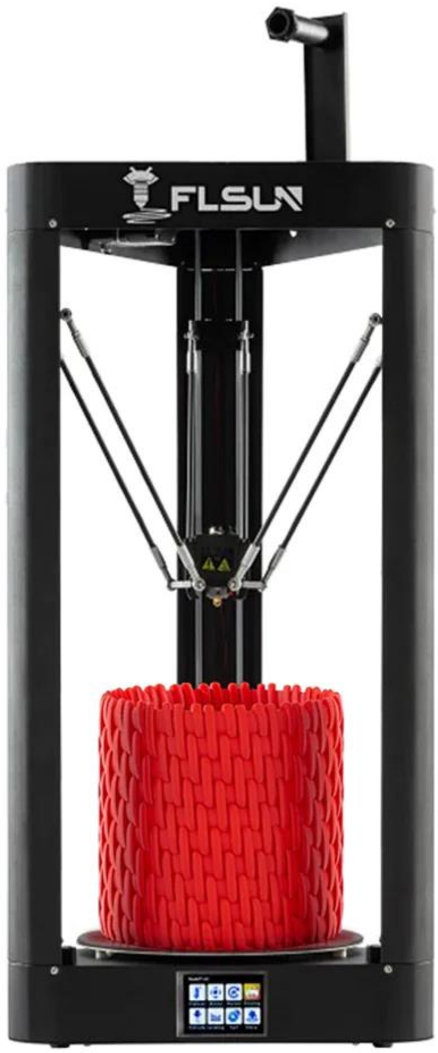

Figure 5. The FLSUN QQ-S pro 3D printer (FLSUN 2023)

3.2 Main components

Aluminum frame:

The frame is made of sturdy aluminum and provides a stable platform for the printer.

Print bed:

The printer comes with a tempered glass print bed that provides a smooth and even surface for printing, shown in Figure 6. It has a build volume of 255mm in diameter and 360mm in height. The print bed measures 265mm but the printable area is smaller because of safety margins.

Figure 6. FLSUN QQ-S pro print bed (FLSUN 2023)

Extruder:

The printer uses a single Bowden type extruder that can handle a variety of filaments, including PLA, ABS, PETG, and more. (FLSUN 2023.)

Figure 7. FLSUN QQ-S pro extruder (FLSUN 2023)

Control board:

The printer uses a 32-bit control board with a touch screen interface that allows you to control the printer settings and monitor the printing process. (FLSUN 2023.)

Power supply:

The printer comes with a 24V power supply that provides the necessary power to run the printer. (FLSUN 2021a.)

Motors:

The printer uses three stepper motors to move the print head along the Z-axis, and one motor for the extruder. (FLSUN 2021a.)

Hot end:

The hot end is located on the effector cage. (FLSUN 2021a.)

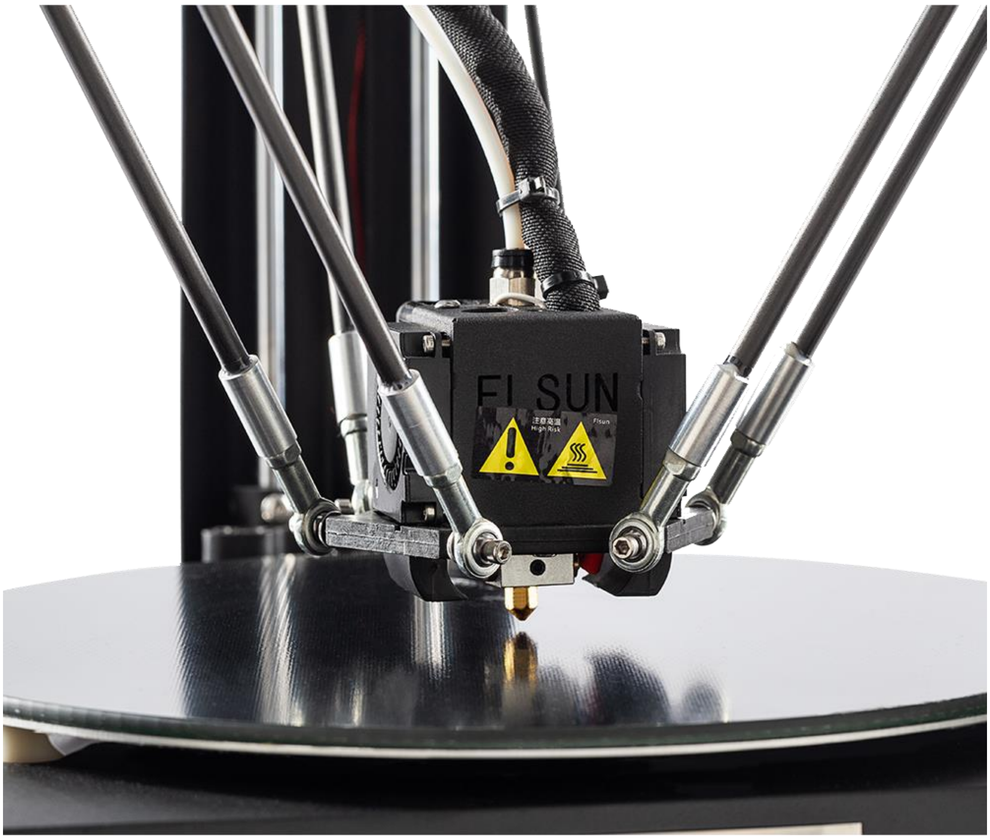

Figure 8. FLSUN QQ-S pro effector cage (FLSUN 2023)

3.3 Bill of materials

The bill of materials lists all the parts that come with the stock version and are necessary to assemble the printer. If parts need to be replaced, their designations can be found here. The bill can help with modifications as well, if one is uncertain about their compatibility. Last but not least, the printer can be checked for missing parts, if it is bought as a used good or disassembled.

To provide an overview the printer is split into the following subassemblies:

Tower:

- 3x ABS rod mounting base
- 3x ABS rod mounting top
- 12x M4x10 bolts
- 6x 8mm rod
- 3x GT2 6mm timing belt, 1486 mm long (Have a spare)
    - Gates brand is recommended
- 3x 1m 2 core ribbon cable
- 6x JST, 2 pin female connector

Carriage:

- 6x Graphite impregnated bronze bushings
    - ID: 8mm
    - OD: 15mm
    - L: 24mm
- 3x ABS carriage

Effector:

- 1x Aluminum effector plate
- 1x hot end mounting cage
- 1x PTFE Tubing (Have a spare)
    - Capricorn brand is recommended
- 1x 40x40x20 (4020) fan (Have a spare)
- 2x 40x40x10 (4010) blower fan (Have a spare)
- 2x ABS fan shrouds
    - It is recommended to replace these with more "on point" ones, PETG is a suitable material

Hot end:

- 1x XCR BP6 block (Have a spare)
    - Can be replaced with V6 block
- 1x MK8 0.4 brass nozzle (Have a spare)
    - Can be replaced with V6 nozzle, but you will need another fan shroud
- 1x V6-clone heatsink & throat
- 1x 40W 24V heat cartridge
- 1x Bead thermistor
- 1x PC4-M10 Pneumatic quick connector

Extruder:

- 1x E3D Titan clone
- 1x L shaped metal bracket
- 2x M4x10 bolt
- 1x NEMA17 41mm Stepper motor
    - NEMA17 is the profile
    - 41mm is the length

Electronics box:

- 1x Cheng Liang P360W24V Power Supply
    - Input: 115/230 VAC 50/60 Hz
    - Output: +24V / 15A
- 1x Electronics board
    - Can be multiple versions depending on the model being pro or not, and can be replaced with any board with sufficient capabilities, read more at upgrade guide
- 1x ~2m, UL2547 9 core cable with 20 AWG cores
- 1x ~2.2m 4 core ribbon cable with 20 AWG cores (for the stepper motors)
- 1x 9 pin GX20 (aviation) connector
    - can be replaced with anything that fits into a 19mm hole and is secure enough
- 3x NEMA17 41mm Stepper motor
- Makerbase MKS Robin TFT_V2.0

(FLSUN 2021a.)

3.4 Maintenance

Contact surface lubrication:

The tower rods and fisheye bearings need lubrication regularly. Lithium grease is easy to apply and the first choice following the manufacturer guidelines. Otherwise, mineral oil can be used, although it needs to be applied more frequently. (FLSUN 2021b.)

During the process the print bed should be covered with paper towels to prevent spillage and therefore the need for cleaning. (FLSUN 2021b.)

The effector can be moved by hand to distribute the lubrication on the rods and check if the amount of lubricant used is sufficient to ensure minimal resistance. (FLSUN 2021b.)

Hot end maintenance:

The nozzle and heater block need to be cleaned frequently as molten filament can get stuck on the outside during printing. This can be done easily using the preheating function and a clean paper tissue, although one needs to be careful when touching the heated part to avoid burns. When using abrasive filament, the nozzle wears out and needs to be changed. (FLSUN 2021b.)

During the process of changing the heartbreak can unscrew from the heatsink, introducing some clearance in the assembly. One might notice a bigger gap between the heater block ant the nozzle and some room to move the heater block, which means the heatsink is loose and needs to be tightened. Also, the Bowden tube should be tightly fitted against the nozzle. (FLSUN 2021b.)

Bed cleaning:

The printing bed should be wiped with isopropanol alcohol after every print, especially if there is visible residue from the filament. If the bed levelling and z-axis offset is properly dialed in, the prints and skirts should be easily removable if the bed has cooled down to room temperature. (FLSUN 2021b.)

If the offset and therefore space between the nozzle and print bed is too tight the extruded paths might be very thin and hard to remove from the bed. One might notice the paths become transparent when the z axis offset is extremely tight. In this case the bed can be preheated and wiped with isopropanol to remove the residue.

Also, the bed can be cleaned with dishwashing soap if the residue is too stubborn to be wiped of with isopropanol. If everything else fails, a spatula can be used to scrape the residue off. Although one should be very careful to avoid damaging the coating of the print bed. (FLSUN 2021b.)

Belt tightening:

The belts are tightened using the thumb nuts on the top of the frame. The belts should be tightened until the two sides of the printer are prevented from touching each other while applying light pressure with one’s fingers. Too much tightening can result in damage to the motor mounts causing inaccurate prints. (FLSUN 2021b.)

If the belts cannot be tightened enough even though the thumb nuts are at their maximum, the belt might be damaged or stretched out. If any damage is noticeable the belt needs to be changed. A stretched-out belt can also be shortened. (FLSUN 2021b.)

4 PRINTER REPAIR

Leveling and offset failure:

When the printer was obtained and boot up the first time, the auto leveling sequence failed and the configuration of the zero position for the z-axis did not work as well. Suspectedly the firmware did not support the updated stepper drivers, which were already installed by the previous owner. Their higher step resolution could cause issues with the standard configuration.

After a firmware update to the newest version, which is specifically adapted to support the new stepper motor drivers, the levelling sequence and offset configuration work without any issues. Since it is a commonly applied update for this specific printer, a firmware version that supports the new drivers, is provided by the manufacturer FLSUN.

Extruder abrasion:

The filament flow provided by the extruder was not sufficient, resulting in parts full of gaps between the outlines of the prints. Also, a weight difference to the specified value given by the Cura slicer of approximately 10-25% was noticeable. Therefore, the structural integrity of the prints was heavily reduced.

Since the issue only occurred during printing the inner lines or infill, suspectedly the extruder did not grab the material well and slipped when trying to push the filament. The outer walls of the print are printed with only 50% of the set print speed of 60 mm/s, which makes it easier for the extruder to push the filament.

The issue could be compensated by increasing the filament flow rate in the slicer settings to 110-115%. Values between 110% and 125% have been tested. This achieved the right weight, similar to the provided values from the slicer and improved the strength of the print.

Nonetheless, the quality of the outer walls decreased due to over extrusion at those areas. Since the flow rate is usually changed for the whole print, the higher value was too much for the outlines because the extruder did not slip as badly there.

To solve this issue the printing speed would have to be dialed down to around 30 mm/s. At this speed the extruder is working more reliably. Nevertheless, delta printers are often chosen because of the high printing speed. This issue obviously diminishes that advantage. Therefore, it would be more suitable to exchange the extruder for a one that features dual drive and does not cause this kind of abrasion.

Overall, the higher flow rate helped with the prints stability, which is crucial to most parts. Because of that the flow rate was changed permanently in the configuration file. Using only the slicers compensation feature would cause issues to other users, which do not know about the issue. The over extrusion on the outer shell is not as problematic, since it is mostly a cosmetic issue. It can be accepted if the extruder is not to be changed.

To change the extruder step value in the configuration file the file needs to be opened on a PC. It can be found in the firmware data and is a simple text file. There the e step value has to be changed. To calculate the right value, a certain distance is marked on the filament spool at the inlet of the extruder. On the display the same distance can be pulled in using the extrude function in the settings. If the extruder does not pull in the correct amount of filament, the difference can be measured and the actual distance pulled calculated. This initially marked distance is then divided by the actual distance and the e step value is multiplied by the result. This can be done several times until the extruder is pulling the right amount. (FLSUN 2021c.)

There is also a calculator available online to help with the calibration of the extruder steps. The marked distance in the instructions is chosen a bit higher than the extruded distance to help with measuring. This has to be accounted for. (Teaching Tech n.d..)

Fan malfunction:

The cooling fan for the heat sink has issues starting up by itself. Although after an initial push to start the rotation, the movement can be maintained. This indicates that the initial moment of inertia of the fan is too high to be overcome by the fans motor. Therefore, the fan should be replaced.

Stringing:

Using Prusa slicer with standard settings for the FLSUN printer a lot of stringing occurred on traveling paths. Compared to the standard settings from Cura slicer for the FLSUN QQ-S pro the retraction distance and speed are set lower, which likely caused the issues. The values from Cura slicer seem to be more appropriate and do not cause the same stringing issues. The settings in Prusa slicer therefore need to be adapted. The retraction distance should be at least 6,5 mm/s and a retraction speed of 25 mm/s is sufficient. Higher speeds can cause issues with filament abrasion using the standard extruder.

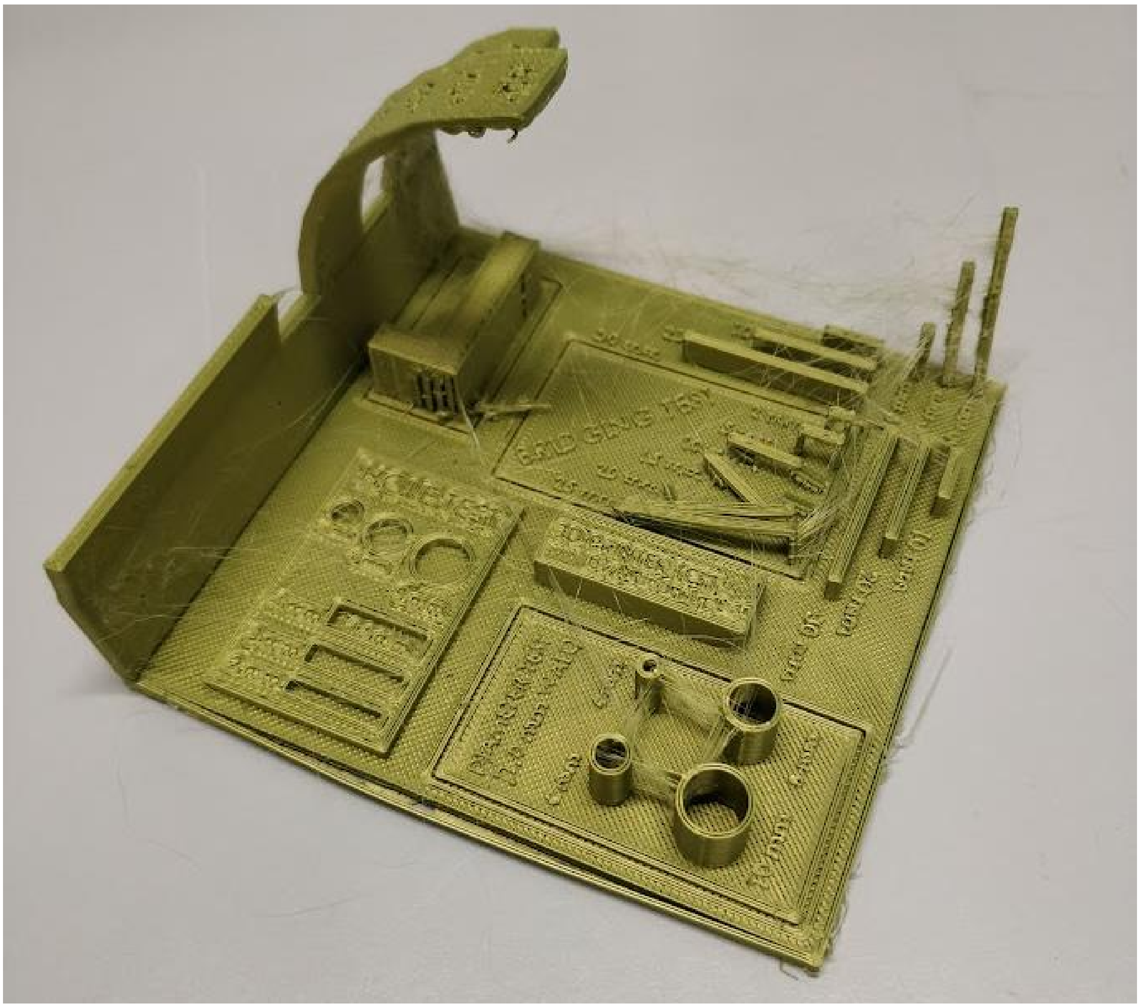

Figure 9. Stringing issues

5 PRINTER MODIFICATION

5.1 Possible upgrades

Print bed:

A PEI coated steel spring print bed is an easy upgrade, since it can be glued on the existing glass hot bed. It has a magnetic plate which sticks to the glass and a coated steel plate, that is caught by the magnet and can be removed quickly. (FLSUN 2021d.)

Stepper drivers:

Silent drivers for the stepper motors can be installed on the mainboard. They reduce the overall noise produced by the printer and also improve the print quality. The e step values in the configuration file of the printer would need to be changed, but the changes are already implemented in an adapted firmware version, available from the manufacturers website. (FLSUN 2021d.)

Quick connectors:

If wired parts of the printer need to be swapped out frequently the cables can be modified with quick connectors. Thereby the user can exchange parts more quickly, not having to crimp cables or pull them from their channels. (FLSUN 2021d.)

Bearings:

The QQ-S pro comes with bronze bushings in the carriages. Those can be exchanged with linear bearings, which might improve friction between them and the rods. Plastic bushings can be used as well but wear out faster than the original ones. (FLSUN 2021d.)

Fans:

Noctua fans for the main board, stepper drivers, power supply, heat break and print cooling are a common upgrade among enthusiasts online, since they are considered to be more efficient and silent than the original ones. Noctua is an Austrian company specialized in fan design and production. (FLSUN 2021d.).

Extruder:

The factory extruder does have issues with slippage and abrasion of filament when used with high feed rates about 50-90 mm/s. Although such high rates rarely occur during printing even at printings speeds up to 120 mm/s. Also, the retraction speed during traveling paths does not need to be higher than 25 mm/s, if the printing speed is at 60 mm/s.

Nonetheless the extruder can be switched for an all metal one, which has higher durability or a dual drive extruder, which grabs the filament between two actively driven gears reducing the rubbing during higher feed rates.

The extruder is mounted on the frame of the printer using a NEMA17 face plate, which should be considered when upgrading the extruder to prevent the need of adapters or buying a new face plate (FLSUN 2021d.).

An E3D Titan extruder would be the most direct replacement, since the factory one is a clone of it. Therefore, there would be no need for additional changes. Also, there are some other clones of this specific type of extruder available at a cheaper price than the original. (FLSUN 2021d.)

A different extruder popular among enthusiasts online seems to be the Bondtech BMG, which also has cheaper clones available. This one provides some advantages such as dual drive, but requires some changes in the software configuration of the printer since it has a different gear ratio in its transmission. (FLSUN 2021d.)

Extruder mounting:

The extruder mounting can be changed if one wants to shorten the Bowden tube. This can improve retraction quality and force transmission over the pushed filament, by reducing the way the filament has to overcome. (FLSUN 2021d.)

A tower shroud mount is possible with the FLSUN QQ-S pro (FLSUN 2021d). In this approach the extruder is placed on the frame at middle height of the printer (Thingiverse 2019a), which allows the Bowden tube to be shortened, thereby improving the force transmission to the hot end. Therefore, retractions of the filament can be performed slower and by a smaller distance, which reduces abrasion to the filament within the extruder.

A top mounted arm is aiming to do the same thing (FLSUN 2021d), but uses a separate arm that holds the extruder on the middle height of the printer (Thingiverse 2021a), without attaching it to the frame. This could reduce the spread of vibrations in comparison to the tower shroud arm, but would have to be investigated to confirm that claim.

In the flying extruder approach (FLSUN 2021d) the part is suspended by three springs from the top of the printer (Thingiverse 2020a), which keeps the weight distribution evenly spread. Vibrations on the frame should be kept to a minimum, since the extruder hovers on the springs. If the Bowden tube is cut very short, that could introduce some tension to the hot end by forcing it to drag the extruder downwards, lengthening the springs. This could worsen the print quality and accuracy.

The direct drive extruder (FLSUN 2021d) is mounted on top of the effector cage eliminating the need for a Bowden tube between them (Thingiverse 2020b). Thereby the force transmission is excellent, allowing retractions to be performed slow and a minimal distance only. On the other hand, it introduces extra weight to the effector cage, which gives it a higher moment of inertia, possibly worsening the accuracy of its movements and thereby the print quality.

This is also why most delta printers make use of the Bowden tube instead of using direct drive like many cartesian printers. With high print speeds the weight of the effector cage becomes increasingly critical to the print quality and should be kept to a minimum. On the other hand, the filament retractions need to be performed faster, which can lead to increased abrasion in the extruder and thereby issues with the filament supply to the hot end. Using a high-quality extruder can help with that.

Optical end stops:

The original solution to stop the carriages at the end of the rods are mechanical switches. Those prevent the carriages from traveling too far up and crashing into the top of the printer. These end stops can be replaced with optical switches, which do not wear out mechanically and are more precise as well. (FLSUN 2021d.)

Filament sensor:

A filament sensor can interrupt prints if the printer runs out of material. The prints can then be resumed if the user supplies new filament. The original configuration does not feature a filament sensor, but the firmware supports it already. Therefore, it only needs to be installed and connected to the main board (FLSUN 2021d). Although some filament sensors polarity needs to be reversed by switching the cables in the socket for them to work. The manufacturer provides a printable adapter as STL file, which is linked in the description of their explanatory video (FLSUN 2020).

Linear rails:

The original guide rods for the carriages can be replaced with linear rails (FLSUN 2021e). To do so new carriages and a new frame would be needed, since the guide rods are an essential part of the frame. 3D printed adapters could mount the linear rails to them, but that would likely cause a loss of printable area. A more suitable approach would be to install aluminum profiles instead of the rods, which the linear rails can be screwed to directly.

Enclosed print chamber:

The frame of the QQ-S pro can be used as a base for an enclosure, since it already goes around the maximum dimensions of the printer. Plexiglass or cardboard could be used to close off the open sides of the print area, although adapters would be needed to offset the enclosure due to the slight overhang of the print bed.

Mainboard switch:

The duet 2 mainboard and duet smart effector for delta printers would be a possible upgrade for the QQ-S pro (FLSUN 2021e). The smart effector has a built-in pressure sensor, which replaces the detachable leveling switch. This could result in more accurate leveling, because the nozzle can be used directly as a leveling switch, leaving less room for error (Duet3D n.d.).

Klipper firmware:

Klipper is an alternative firmware that can be installed on the mainboard. To use Klipper a secondary processing unit such as a microprocessor or a smartphone is needed, which then does most of the calculation that is usually done by the mainboard (Klipper3D n.d.). Some mainboards run at their limits of processing power when executing g-codes, which can lead to micro interruptions during the print and thereby issues with the print quality.

With the Klipper firmware on an application processor the stepper motor commands are calculated and sent to the mainboard in a compressed manner. This leads to more precise printer movements. Also, the firmware configuration can be changed easily, without the need to reflash the mainboard. Issues with hot end pressure or vibrations can be accounted for. Furthermore, the Klipper g-code is written mostly in Python programming language, which is more user friendly and can be changed to introduce new functionality. (Klipper3D n.d..)

5.2 Modified parts

Print bed:

A PEI coated flexible build plate from FLSUN was applied on top of the glass plate. The product is made to fit the FLSUN Super Racer 3D printer but since the print bed has the same diameter it fits the QQ-S pro as well. The product contains two parts, a large magnet with an adhesive applied on the bottom surface, that covers the whole glass bed and a powder coated metal plate, that sticks to the magnet. (3DJake 2023a.)

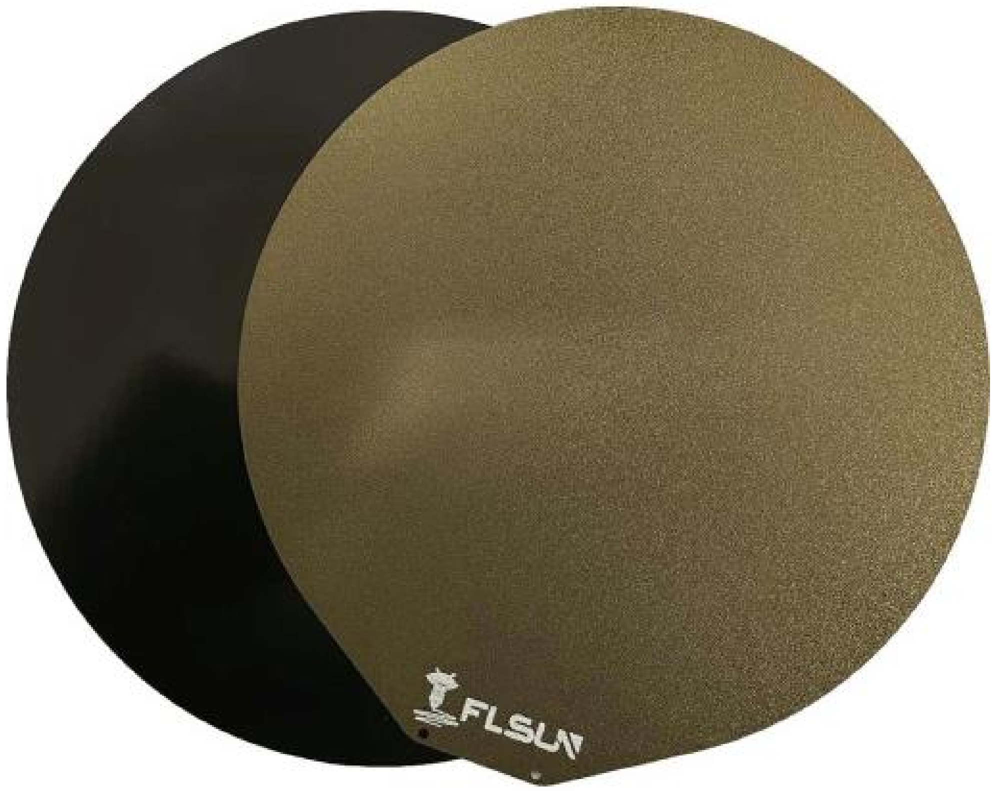

Figure 10. Print bed upgrade (3DJake 2023a)

Stepper drivers:

The four stepper motor drivers were changed to the TMC 2208 silent drivers. FLSUN offers a firmware version to download, which supports the alternative stepper drivers and was installed on the printer. The drivers work without any issues.

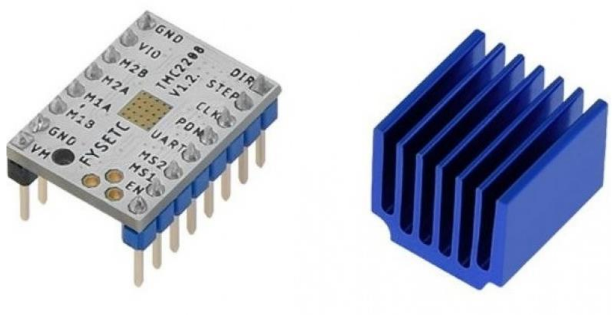

Figure 11. Stepper driver upgrade (Tiny Tronics 2023)

Bearings:

The originally installed bushings were exchanged with six BROZZL LM8UU linear bearings (3DJake 2023b) to decrease friction on the rods and increase precision of movements. They also need less lubrication and cause less abrasion.

Figure 12. Bearing upgrade (3DJake 2023b)

Fans:

Three fans from Noctua were installed on the printer. One NF-A4x20 fan (3DJake 2023c) to replace the heat sink fan on the effector cage and two NF-A6x25 fans (3DJake 2023d) to replace the original fan in the bottom of the printer, which are supposed to cool the main board and power supply. The Noctua fans should run more quietly and efficient.

The original heat sink fan and the main board fan have the same measurements as the replacements. Therefore, the replacement fans work without any issues. The power supply fan has different measurements as the original one. The FLX version of the fans was chosen since the main board does not support PWM.

Figure 13. Fan 4x20 upgrade (3DJake 2023c)

Figure 14. Fan 6x25 upgrade (3DJake 2023d)

The fans are rated for 12V DC unlike the original ones, which are rated for 24V. Therefore, three LM2596S BIGTREETECH DC-DC stepdown modules were installed to set the right voltage for the new fans (3DJake 2023e).

Figure 15. Stepdown module (3DJake 2023e)

Extruder:

The stock extruder was replaced with a BondTech Extruder BMG – Left (3DJake 2023f) which utilizes dual drive and is more reliable. The left-hand version of the extruder was chosen because it spins in the same direction as the original extruder and is reachable from the front better than the right hand one. Otherwise, the direction would have to be changed in the configuration file.

Figure 16. Extruder upgrade (3DJake 2023f)

Filament sensor:

A B1 BIQU filament sensor (3DJake 2023g) was installed, which the printer did not feature before. Although it is supported by the firmware and the main board has a free socket for it. The firmware needs to be adapted to activate the sensor.

Figure 17. Filament sensor (3DJake 2023g)

Bowden tube:

The Bowden tube was replaced with a Capricorn TL Transparent PTFE Bowden due to wear and tear on the original part. The replacement tube is rated for filament with 1,75 mm. Its original length of 1 m was cut to the right size of 600 mm. (3DJake 2023h)

Figure 18. Bowden tube upgrade (3DJake 2023h)

5.3 Printed accessories

Extruder mount:

A 3D printed top mounted arm was chosen to hold the extruder and the filament sensor. This reduces the length of the Bowden tube and could help to isolate the frame from vibrations caused by the extruder. Due to the shorter tube the feed produced by the extruder is transferred better to the hot end. This improves reaction time and therefore also helps when using retractions.

Three different arms were tested, which all are designs from the Thingiverse community. The original design (Thingiverse 2020c) and a remix of it (Thingiverse 2021a) both needed to be shortened with Meshmixer to fit in the print chamber of the Ultimaker S5. The mounting plate for a filament sensor, which the remix features does not align the sensor properly with the extruder filament intake, therefore a custom one was designed.

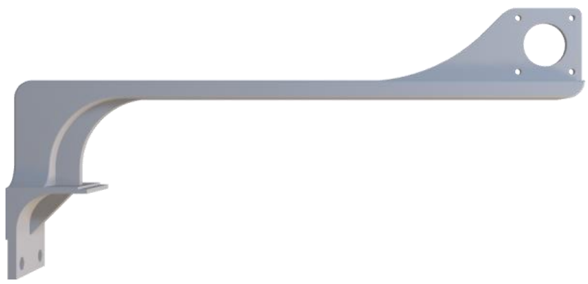

Figure 19. Original extruder mount (Thingiverse 2020c)

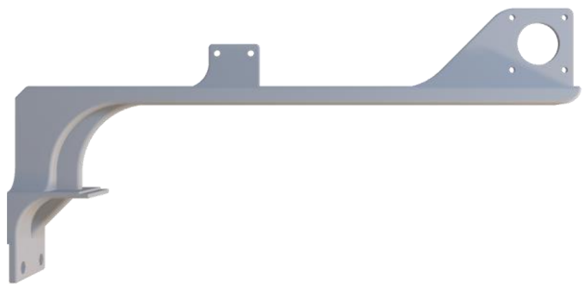

Figure 20. Remixed extruder mount (Thingiverse 2021a)

The design of the custom arm was inspired by the ideas from the Thingiverse community (Thingiverse 2021a), but the model was rebuilt on Autocad Inventor to be able to adapt it. The new model is slightly smaller to be manufacturable with the Ultimaker S5 and was modified to be printable with less support structure. A mount for a filament sensor was placed on the arm in a new position. The final version was printed in PLA, with 50% infill density and no support, on the Ultimaker S5.

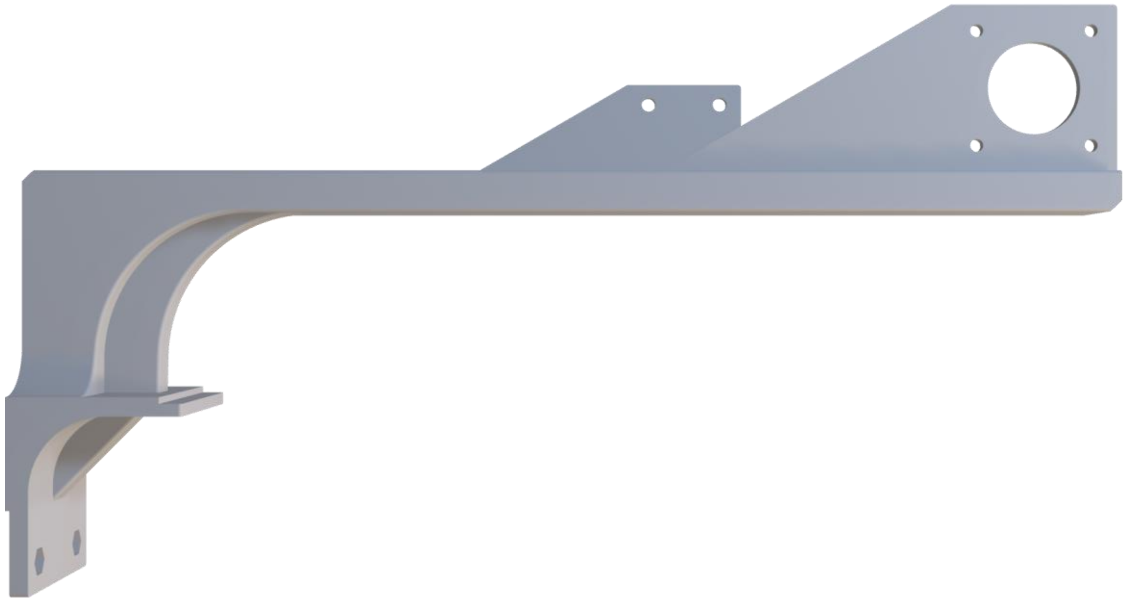

Figure 21. Own design of extruder mount

Buck converter box:

To mount the buck converters and prevent its electronic parts from being damaged or adjusted by accident, three boxes were 3D printed. The converter snaps in place on the bottom part of the box and the cover snaps on top. To provide ventilation the box has a honeycomb shaped structure in both the cover and the bottom. The design was created by the Thingiverse community (Thingiverse 2021c). It was printed on a Prusa i3 as a solid part using PLA. No support structure was needed.

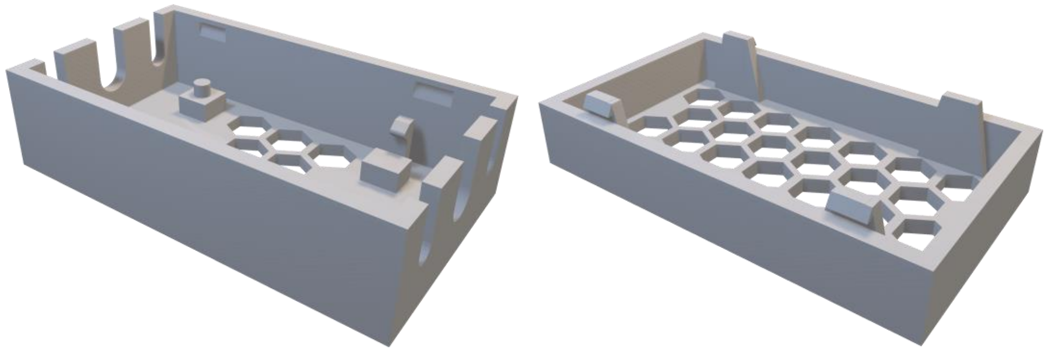

Figure 22. Buck mount (Thingiverse 2021c)

Power supply cover:

To make room for the new cooling fan, a cover for the power supply was 3D printed. It has a slot specifically designed to fit the fan size which holds it in place. The design can be found on the Printables website (Printables 2022). The part was printed on a Prusa i3 using PLA, 50% infill density and support structure on the build plate.

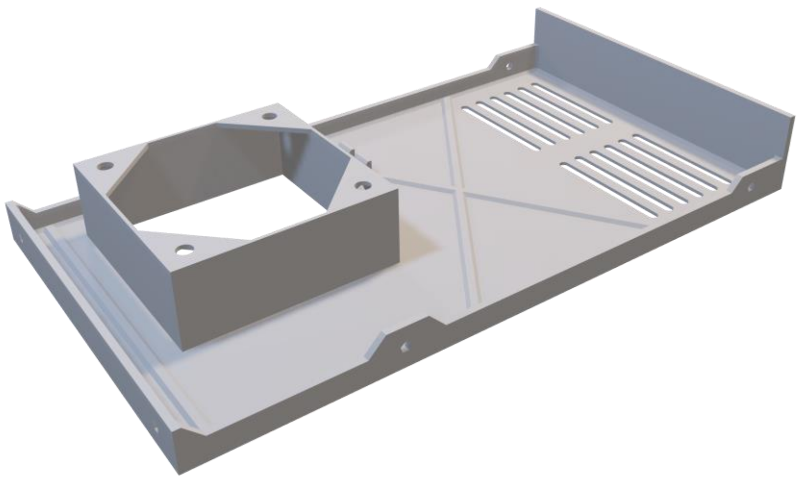

Figure 23. Power supply cover (Printables 2022)

Filament spool holder:

The original filament spool holder was modified with 3D printed parts. The new design fits wider filament spools and can hold a second spool. The design was made by the Thingiverse community (Thingiverse 2021b) an printed using PLA, with support on the build plate, 50% infill density and an Ultimaker S5.

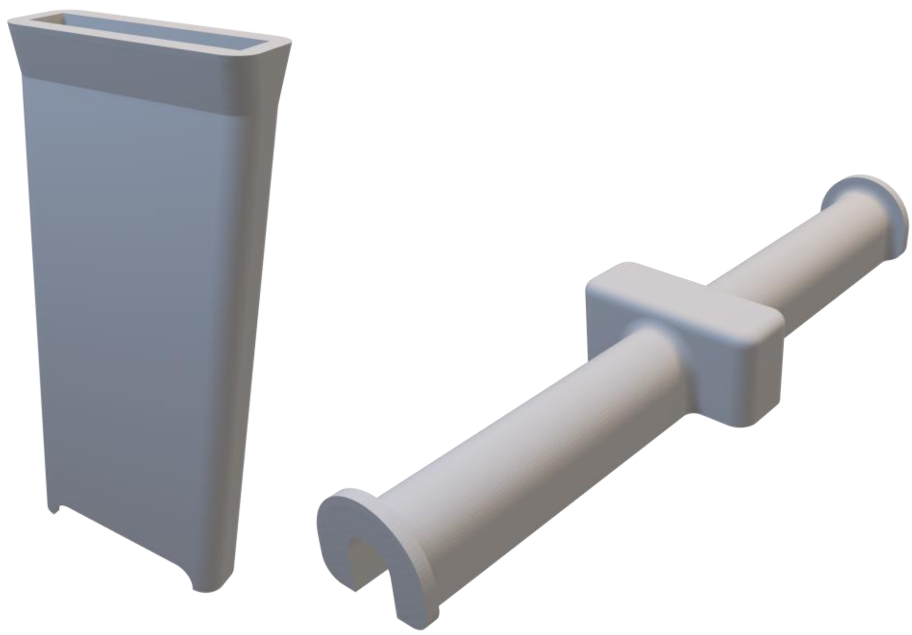

Figure 24. Filament spool holder (Thingiverse 2021b)

Fan ducts:

Several 3D printed fan ducts were tested and compared to each other. The original ones do not focus the airflow properly onto the nozzle tip and the airflow is not centered.

The first design (Thingiverse 2022a) focuses the airflow best but sits loosely on the effector cage, causing the ducts to be able to touch the hotend and melt. Also, they are hard to install and remove and can break during the process.

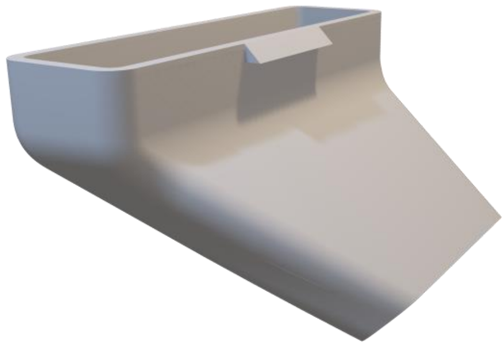

Figure 25. Fan duct (Thingiverse 2022a)

The second approach (Thingiverse 2020d) sits sturdy on the effector cage, is easy to install and remove, but does not focus the airflow well onto the nozzle. Thereby the cooling effect is not optimal.

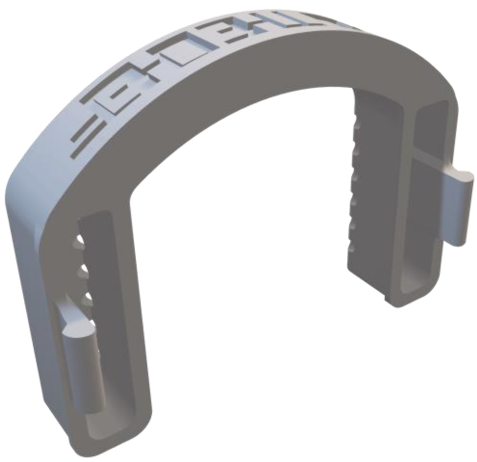

Figure 26. Fan duct (Thingiverse 2020d)

Tested third was another design (Thingiverse 2022b), which has a screw mounted base and therefore is extremely sturdy. The ducts can be slid into the mounting base and do not move once installed. The airflow is directed onto the part but not directly at the tip of the nozzle. Also, the ducts can touch the print because they sit almost as low as the tip of the nozzle.

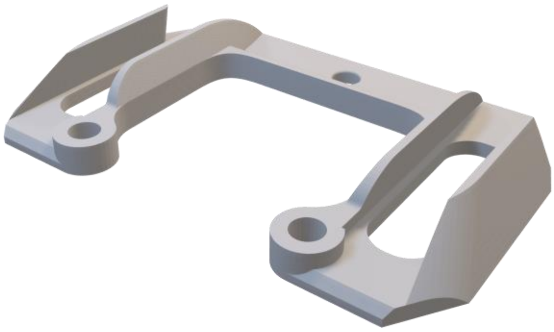

Figure 27. Fan duct mount (Thingiverse 2020d)

To combine the best features, new fan ducts and a mounting plate were 3D printed to replace the original ducts. The outlet of the new ducts is smaller and focuses the airflow more precisely on the end of the nozzle. The mounting plate keeps them from moving and touching the hotend. To hold the mounting plate on the effector cage, the screws that connect the cage cover to its base are used.

The fan ducts were inspired by the first tested ones (Thingiverse 2022a), but recreated and adapted to fit the mounting plate in Autocad Inventor. The mounting plate was taken from the third model (Thingiverse 2022b). The final design was printed on a Prusa i3 using PETG as a solid part. The parts were designed to be printed without support.

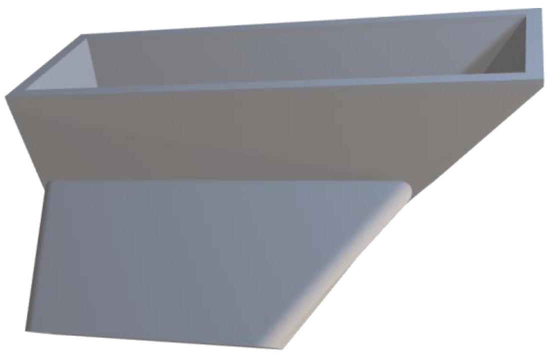

Figure 28. Own fan duct design

Base feet:

To elevate the base higher from the surface, the printer is placed on 3D printed feet, which were attached to the printer. This improves airflow and thereby cooling efficiency in the printer base. The model was sourced from Thingiverse (Thingiverse 2020e). It was printed on the Ultimaker S5 with TPU and 20% infill density. No support structure was needed. The parts were already installed on the printer but needed to be reprinted due to wear and tear.

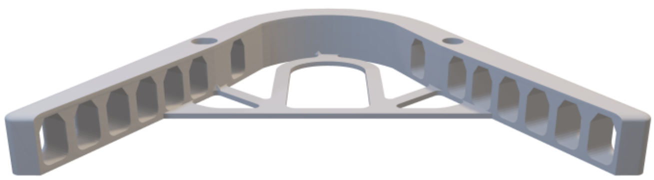

Figure 29. Base foot (Thingiverse 2020e)

Cable management:

The original printer does not have mountings for the cable which connects the top and bottom of the printer. To prevent the cable from dangling into the print area, clamps were 3D printed. They snap to the cable and the frame of the printer, keeping them securely together. The clamps can be found on the Thingiverse website (Thingiverse 2019b). The parts were printed solid on a Pruse i3 using PLA and no support. The parts were installed by the previous owner as well but showed signs of wear and tear.

Figure 30. Cable clamp (Thingiverse 2019b)

To tension the cables of the end stops, which can rub on the carriages of the effector cage, a mechanism was 3D printed and placed behind the bottom of the carrier rods. They were designed by the Thingiverse community as well (Thingiverse 2020f) and printed by the previous owner of the printer.

Rod stabilizers:

To stabilize the rods and reduce vibrations 3D printed parts are used on the bottom and top of the printer. They can be found on Thingiverse (Thingiverse 2020g). The printed parts from the previous owner were reused.

Additional parts:

The printer features even more 3D printed accessories. Since they were installed by the previous owner, they cannot be named. Most of them were left in place and continued to be used. The frame mounted clamps mentioned above were reprinted due to signs of wear and tear.

5.4 Recommended slicer settings

Temperature:

The bed temperature should be chosen according to the filament material specifications. For PLA 60°C is sufficient.

The nozzle temperature should be chosen according to the specifications as well. Although, it can be reduced slightly to have a faster cooldown after the material is pushed out of the nozzle. For PLA a temperature of 215°C is recommended but 200°C does achieve good results as well. If the print involves a lot of bridging the lower temperature could improve the results.

Print speed:

The print speed can be adjusted up to 120 mm/s without major issues, although that might result in prints with lower quality. A speed of 60 mm/s does not cause any issues with print quality. The slower the print speed the better the surface quality and precision of the print. The manufacturer recommends a maximum speed of 100 mm/s with the standard configuration of the printer.

Retraction:

Retracting the filament from the hot end relives pressure and thereby stops the material flow faster. A retraction distance of 6,5 mm at a velocity of 25 mm/s is sufficient when printing at a speed of 60 mm/s. Due to the long Bowden tube those values need to be higher than for most other printers. Faster retraction speeds up to 90 mm/s might be needed when printing at higher speeds up to 120 mm/s. Such fast retractions can cause problems with abrasion within the extruder.

Bed adhesion type:

Preferably the adhesion type skirt should be chosen to reduce postprocessing of the print. The FLSUN printer does not pre-extrude material. Therefore, the skirt provides some room for initial extruding issues, as it is not part of the model. Only if prints fail due to insufficient adhesion to the print bed, a brim should be chosen to increase the adhesive surface.

Combing:

This setting is available in Cura slicer and causes the nozzle to stay over printed areas when executing traveling paths. Even though material is not extruded actively on traveling paths, it can ooze out of the nozzle due to pressure built up in the hot end. That would cause stringing when moving the nozzle over the boarders of the part.

This can be avoided by retracting the material, which can cause issues with abrasion and slippage when done excessively. Enabling combing reduces the need for retractions and is recommended for most models. The print time can be longer when combing is active, since the print head does not travel the shortest distance between two points if the model is curved.

Coasting:

This setting is available in Cura slicer and causes the extruder to stop pushing filament when approaching the end of the path. The material oozing out of the nozzle afterwards then fills the last bit of the path. This can improve printing quality when using high print speeds.

Without this feature the oozing material could cause blobs, sometimes visible on the surface of the part or stringing when the traveling path is leading the nozzle away from the printed area. At traveling speeds over 60 mm/s Coasting is recommended.

5.5 Configuration changes

The configuration file was adapted to work with the modified parts. The extruder steps, filament detection level and length of the Bowden tube need to be accommodated for. Specifically, the following values were changed:

>EXT0_STEPS_PER_MM	405	(previously 367)
>EXT1_STEPS_PER_MM	405	(previously 367)
>cfg_filament_det_trigger_level	1	(previously 0)
>cfg_filament_load_length	650	(previously 800)
>cfg_filament_unload_length	650	(previously 800)

6 PRINTER TESTING

6.1 Test models

The printer was tested with different 3D models before and after modifications were applied to compare differences in the print quality. The chosen test models include:

3DBenchy:

A small ship, which is printable in a short time. It has straight and rounded walls, overhangs and bridges, surfaces with different angles and infill. It is suitable to test the quality of more complex models and includes a lot of the possible operations, that can be performed by the printer, such as retractions, bridging or filament flow. The model was obtained from the Thingiverse platform (Thingiverse 2015).

Figure 31. 3DBenchy (Thingiverse 2015)

AIO test micro:

A variation of the all-in-one 3D printer test, that is much smaller, compared to most other AIO test prints. It still has most test instances present on the print. Overhang quality, tolerance accuracy, occurrence of stringing, scale and diameter accuracy, bridging and quality of sharp corners are displayed on the finished piece. The printing time is much shorter due to the smaller size. The design is found on Thingiverse (Thingiverse 2018).

Figure 32. AIO test micro (Thingiverse 2018)

XYZ Calibration cube:

This model is a cube with 20 mm side length, that allows the user to measure the accuracy of printing dimensions in every axis. Also, the ghosting effect, a shadow of printed geometries due to vibrations, can be observed if present. It mostly is visible on straight walls embossed with writing or other shapes. On the finished wall the embossing will be visible a second time in printing direction, as a tiny dent on the wall surface, if ghosting occurs. The model can be found on Thingiverse (Thingiverse 2016).

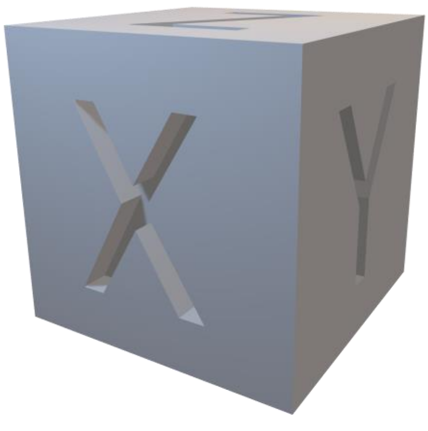

Figure 33. XYZ calibration cube (Thingiverse 2016)

Flow calibration cube:

This variation of the calibration cube has the same measurements as the original one but is hollowed and does not have a top surface. The model is available on the Thingiverse website (Thingiverse 2021d).

The other walls of the print are 0.8 mm thick and therefore will be printed with exactly two material paths if a 0.4 mm nozzle is installed. One can measure the accuracy of wall thickness, which is determined by the flow rate of the extruder.

The cohesion of the wall paths can be checked as well. Mostly due to under extrusion the material paths of the wall can be separated, which leads to the formation of two separate walls. That will worsen the structural integrity of the print by far and causes the wall to bend or break easily.

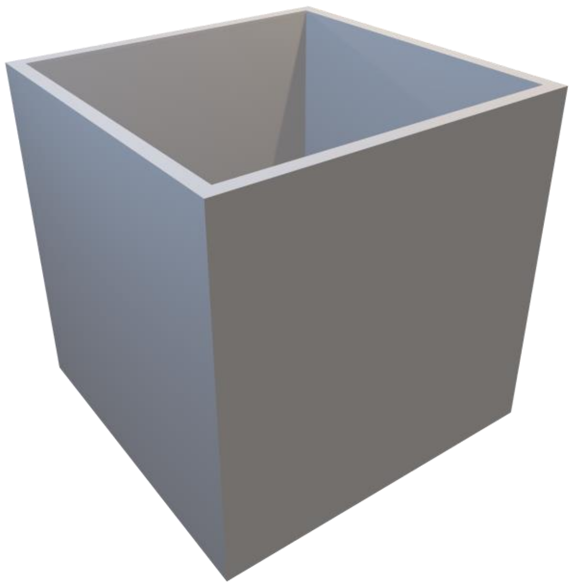

Figure 34. Flow calibration cube (Thingiverse 2021d)

6.2 Test results

The initial configuration of the printer had several issues, which the modifications were supposed to solve or compensate for. The shown test prints were printed at a speed of 60 mm/s for accurate comparison.

Extrusion:

The most noticeable issue was the presence of under extrusion due to abrasion of filament in the extruder and slippage caused by that. The flow rate was only accurate on low print speeds about 30 mm/s.

This was visible on the flow calibration cube, which showed wall separation issues and inaccurate wall thickness. It was printed with a speed of 60 mm/s. The other test prints printed at the same speed, showed holes in the top surface due to interruptions of filament flow, caused by slipping. The micro AIO test even showed layer separation on the finished print.

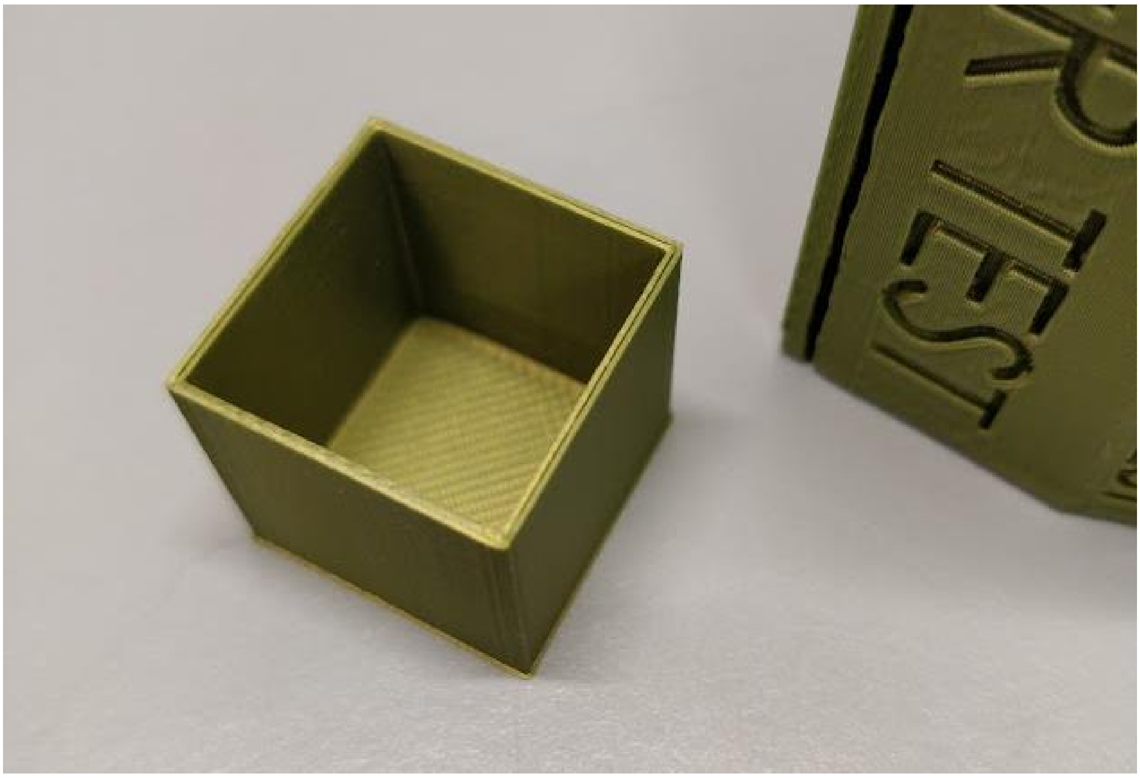

Figure 35. Layer and wall separation

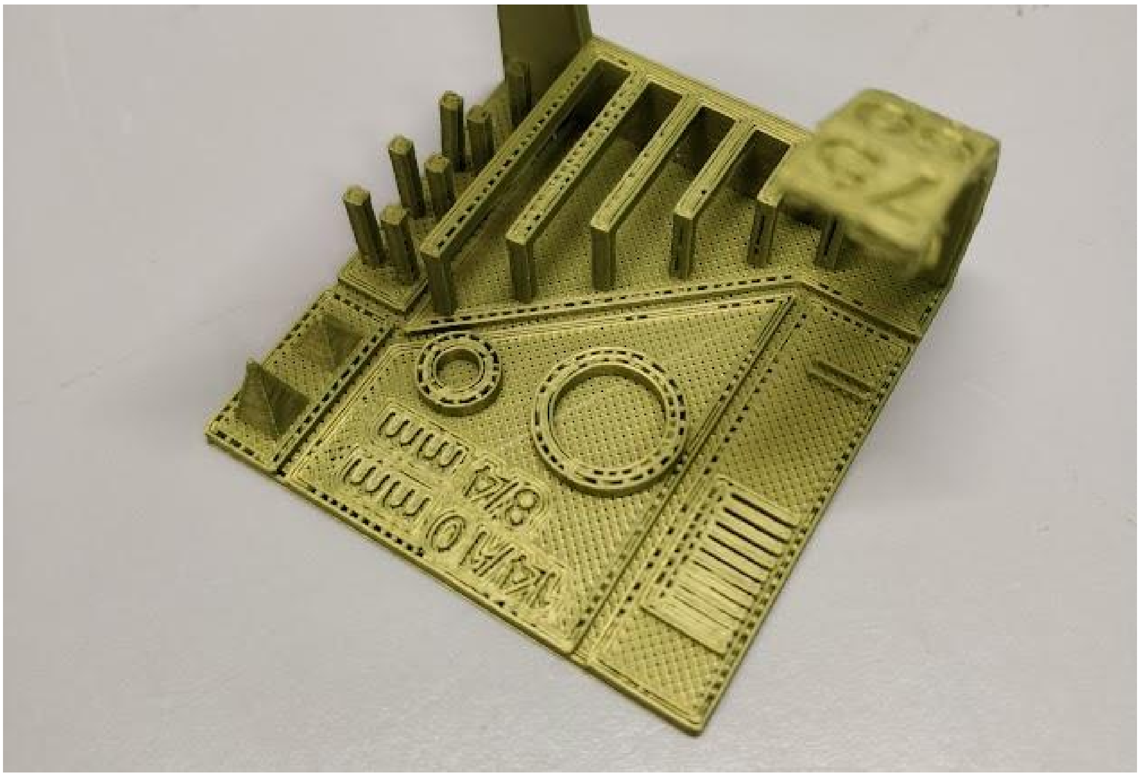

Figure 36. Holes on the part surface

A software compensation of the flow parameter did increase the amount of extruded material on higher speeds, but caused over extrusion on low print speeds. Although, the initial issue of abrasion in the extruder could not be accounted for with changes of the g-code or configuration file.

The over extrusion was visible on the walls of the benchy, where a lot of artifacts were present, meaning blobs of material bulging out of the surface. The corners of the XYZ calibration cube were visibly bent outwards, which also indicates over extrusion.

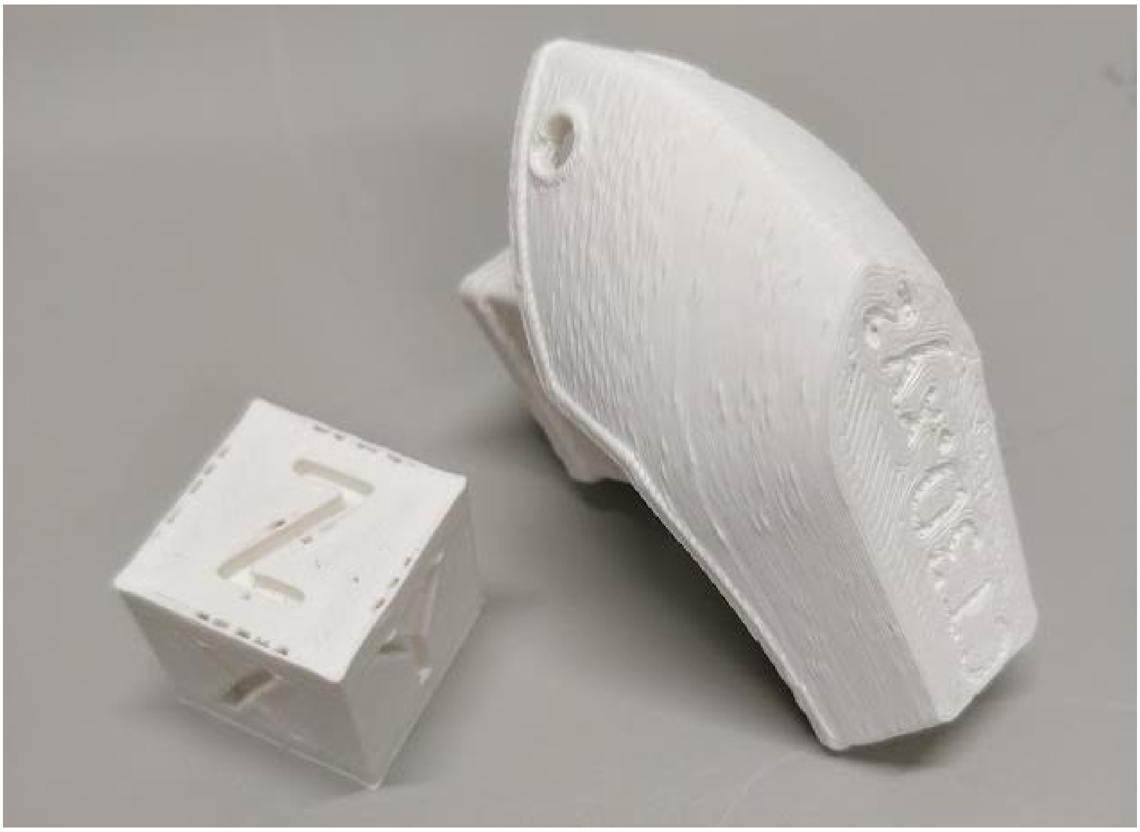

Figure 37. Bent corners, artifacts and holes on the part surface

The new extruder installed on the printer provides a much more reliable filament flow up to speeds of 120 mm/s. Layer and wall separation are not present on the test prints done after the modification. The wall surface quality did improve as well. Some holes in the top surface are still present at high print speeds of 120 mm/s but not at 60 mm/s like before.

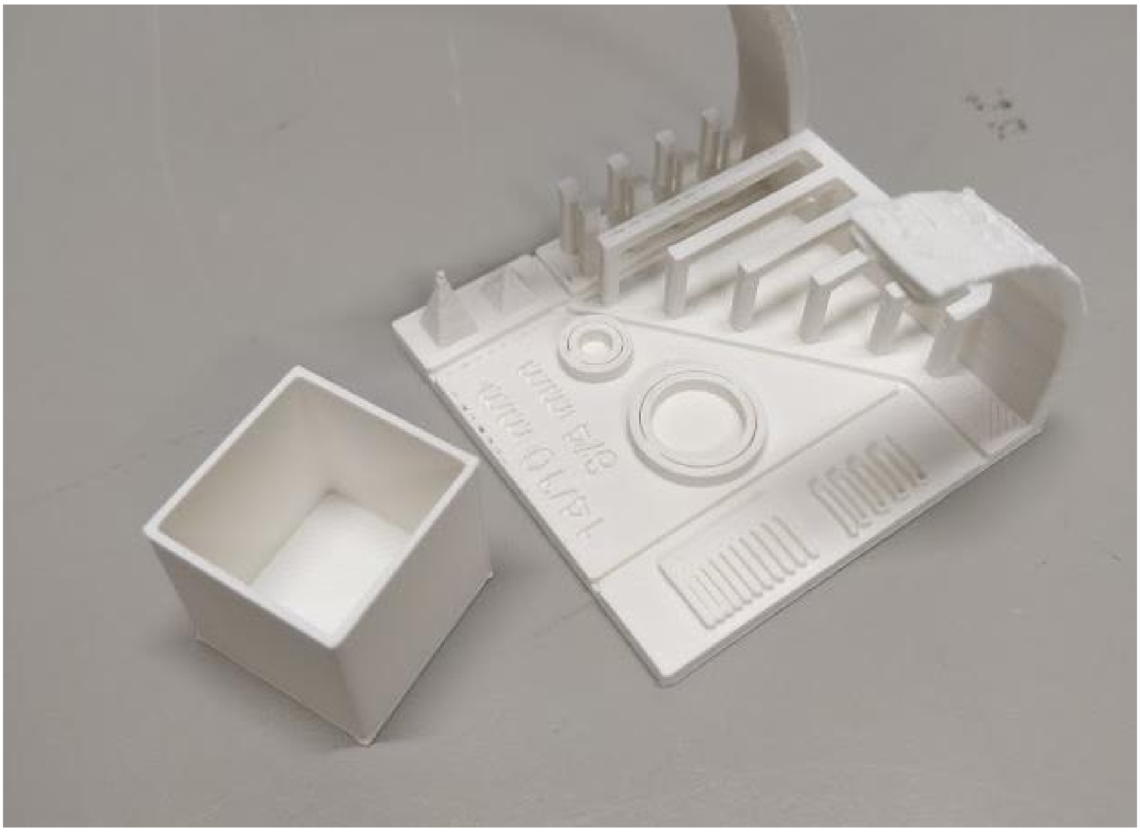

Figure 38. Solid walls and surfaces after modification

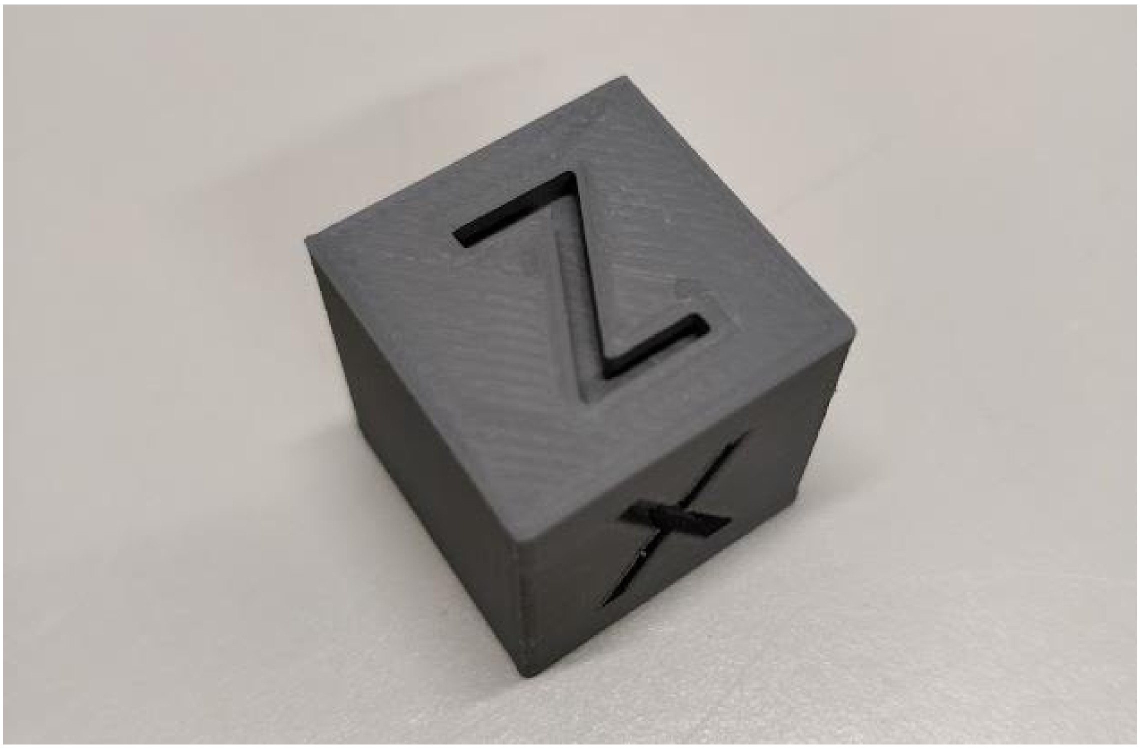

Figure 39. Solid and smooth surfaces after modification

Vibrations:

Ghosting was visible on the XYZ calibration cube especially on higher print speeds, which likely occurred due to vibrations and shaking of the printer frame. A shadowlike second instance of the embossing on the surface occurs in print direction.

The bushings used in the original configuration were suspected to cause resistance when sliding over the rods which the linear bearings installed during modification should improve. The vibrations due to slippage in the extruder were reduced by replacing it and relocating it on the top mounted arm. The test prints after modification show less ghosting, which indicates an improved stability of the printer.

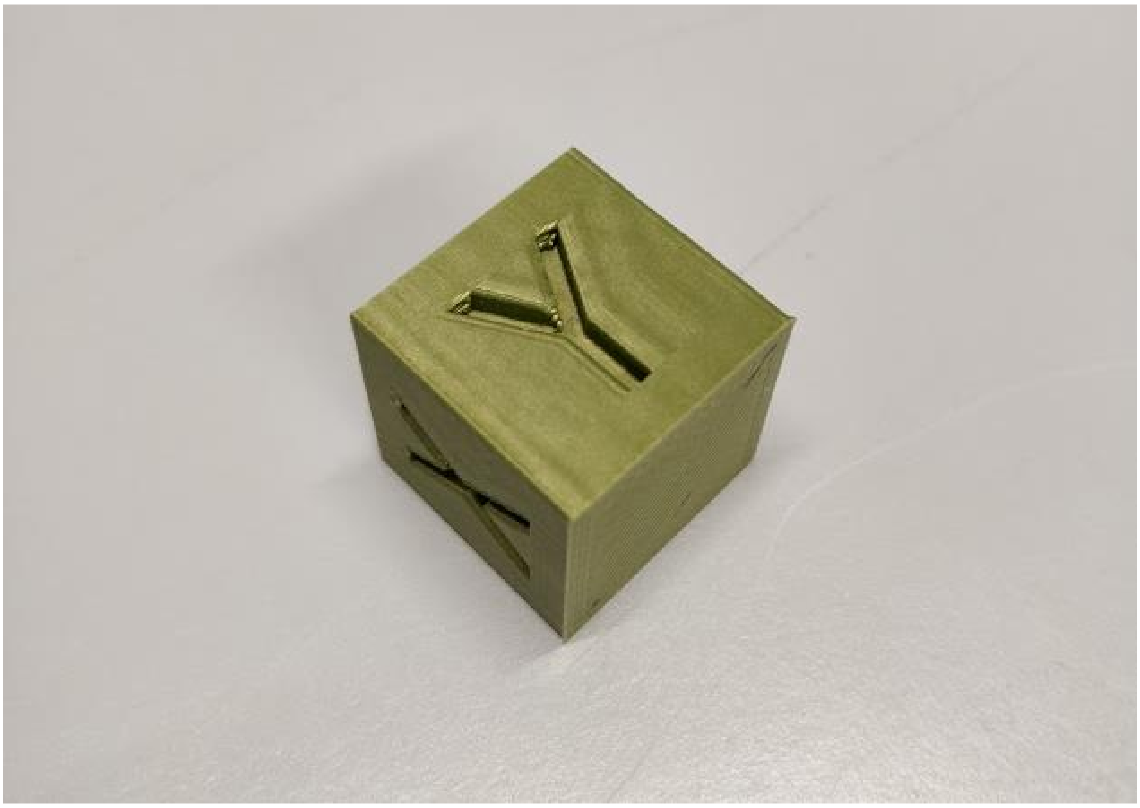

Figure 40. Ghosting due to vibrations

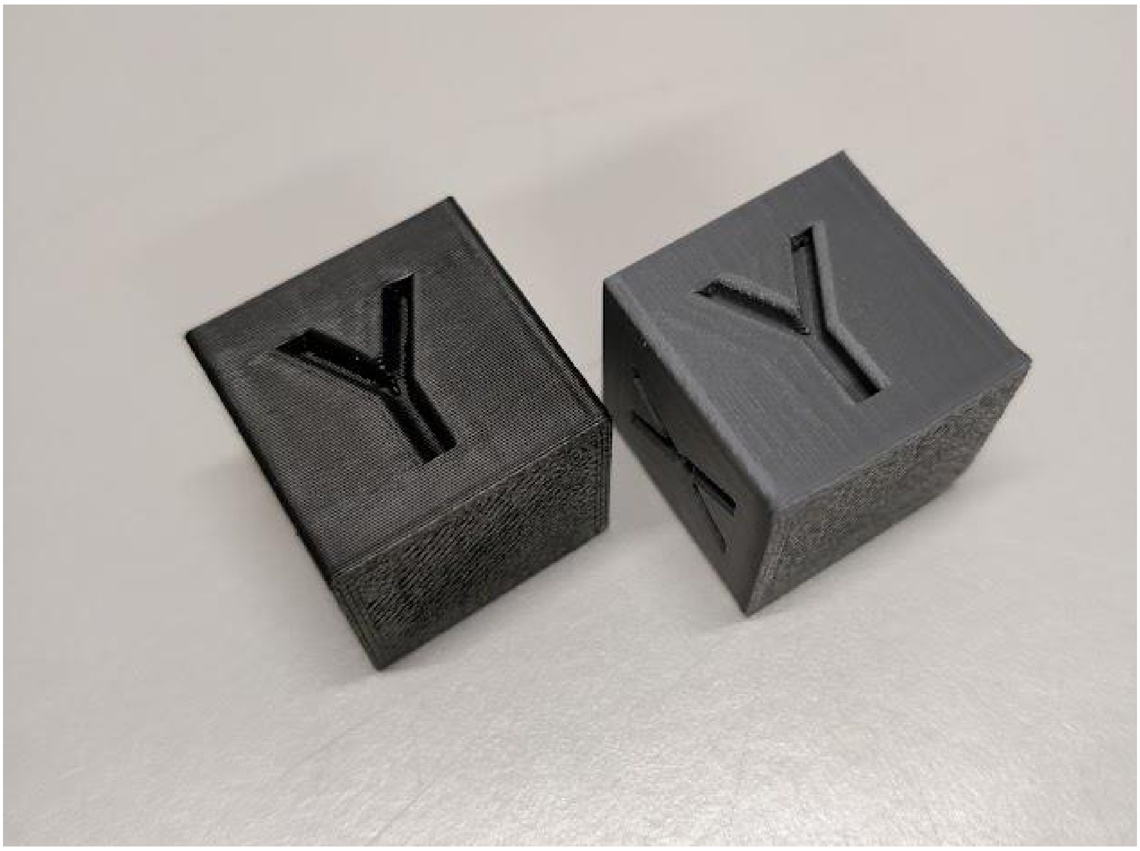

Figure 41. Reduced ghosting after modification

Part cooling:

The print cooling on the original configuration of the printer was improved by the new fan for the effector cage and the modified fan ducts. Both upgrades generate a higher and more focused airflow onto the tip of the nozzle, which cools the extruded material faster. This improves the bridging capabilities of the printer.

Looking at the AIO printer test and the benchy printed before the application of the modifications, some issues with bridging were visible. The tests printed afterwards show less hanging material paths, indicating faster cooling of the extruded material.

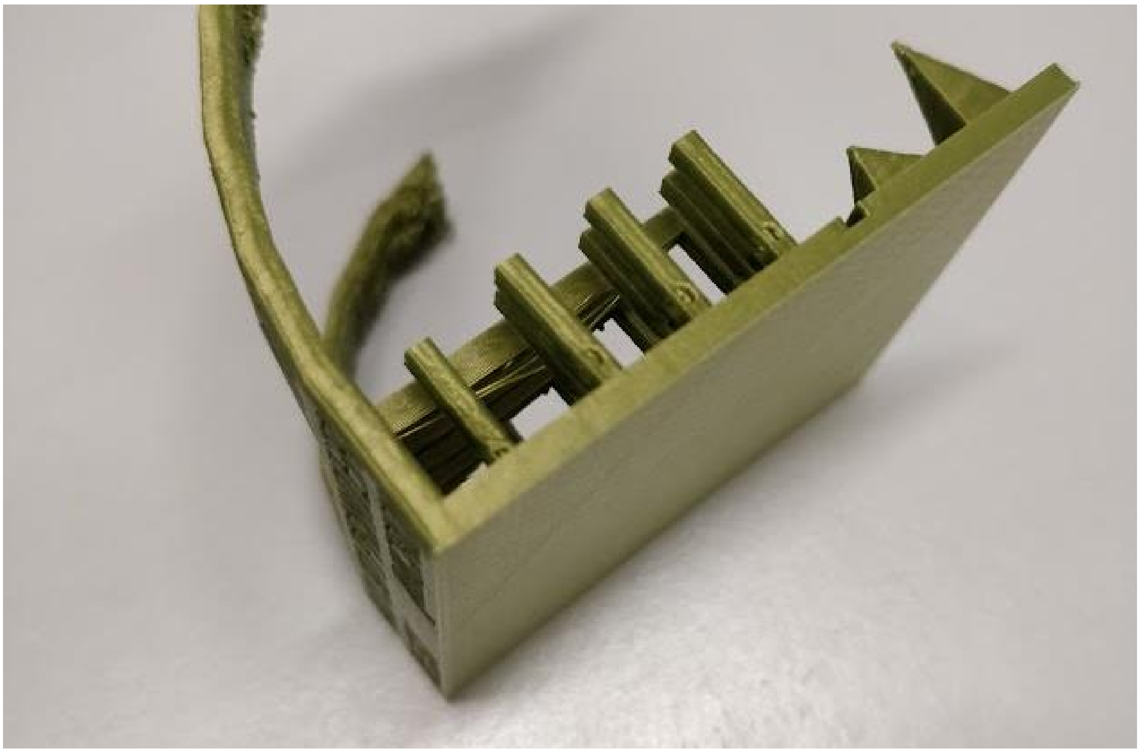

Figure 42. Bridging issues

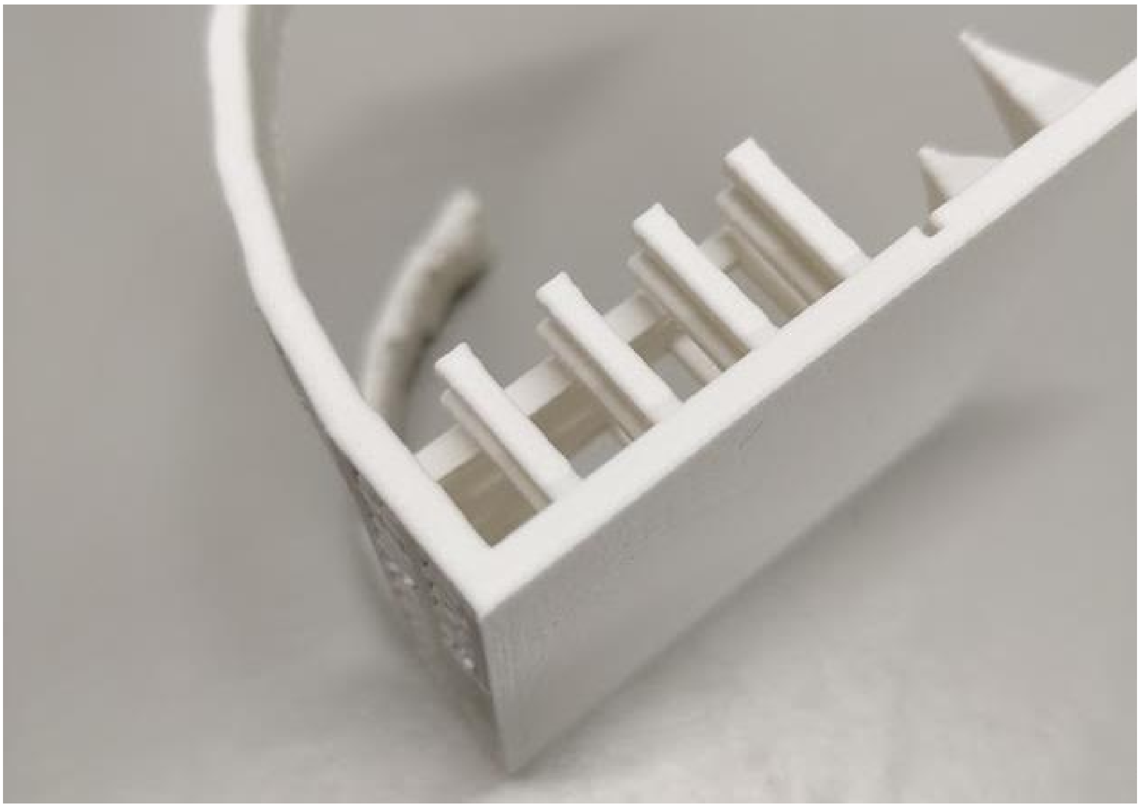

Figure 43. Improved bridging after modification

7 CONCLUSION

Overall, the modifications installed in the printer improved its capabilities. Especially printing with faster print speeds up to 120 mm/s is now possible with less compromise in print quality. Since delta printers are advertised for their fast print speeds, this can be seen as a unique selling point of these machines. Therefore, the possibility to reach high print speeds while maintaining decent print quality is crucial.

Furthermore, a common complaint about the FLSUN QQ-S pro is the noise it produces while printing. A lot of that is caused by the stepper motors or more precisely the stepper motor drivers. This was improved by the application of silent stepper drivers. A further reduction of the noise was achieved by installing silent fans on the printer and replacing the stock extruder with a high quality one.

Even though the print bed adhesion was good on the glass surface of the original configuration, the application of the coated spring steel plate did increase the user friendliness of the printer. Before the upgrade was applied the print was sometimes hard to remove from the bed or residue was left behind, forcing the user du clean with isopropanol or even a spatula. With the upgrade adhesion is still good, but the prints separate much easier from the bed, after cooldown even by themselves. Should the print stick to the surface, the plate can be removed easily and bend slightly to detach the print. This is more comfortable and increases the lifespan of the print bed.

Last but not least, the implementation of a filament sensor allows the user to leave prints unattended and use up almost empty filament spools, without having to worry about print failure.

8 DISCUSSION

To improve the printer even further, the modifications mentioned above, which were not chosen to be installed, could be taken into consideration. Except the linear rails, which will render the linear bearings obsolete, most of them should not interfere with the upgrades installed on the printer.

Especially the main board switch and the smart effector would be an interesting upgrade and could improve user friendliness by getting rid of the leveling switch and therefore the need to put it on and take it off the effector cage continuously. The accuracy of the bed leveling could be improved by that as well.

The application of the Klipper firmware to the printer and outsourcing a lot of computation to a Raspberry Pi or other microcontroller, would be the most useful modification. Firstly, it could relieve the existing mainboard of the most of its duties, possibly improving print quality. Although in this case a mainboard switch would not be that attractive. Secondly, the Klipper firmware could improve usability of the printer by making it easier to apply modifications to the configuration file, not even having to restart the printer doing so. That could be useful when aiming to have interchangeable parts on the printer, such as different hotends or extruders.

Finally, is can be said that the FLSUN QQ-S pro has its unique upsides but limitations as well. The tower like frame will always be prone to vibrations interfering with prints. The delta approach, while being able to realize fast print speeds, is not as sturdy as a cartesian structure.

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