Designing extrusion die for 3D filament manufacturing

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EXAMENSARBETE	
Arcada	
Utbildningsprogram:	Plastteknik
Identifikationsnummer:	13021
Författare:	Matti Lipponen
Arbetets namn:	Design av ett extrusions munstycke för 3D filament production
Handledare (Arcada):	Erland Nyroth
Uppdragsgivare:	

Sammandrag:

Syftet med detta examensarbete var att undersöka om det skulle vara möjligt att producera tråd för 3D skrivaren på plast labbet i Arcada.
Målet i detta arbete var att designa och framställa ett extruderingsmunstycke för att uppnå acceptabel tråd för Minifactory 3D skrivaren.
Arbetet täcker en hel del saker angående om design av munstycken för extrusion samt deras producering.
Tyngdpunkten i detta arbete ligger på bearbetningen av munstycket samt bearbetningsprocesserna fräsning och borrning.
Arcada försedde verktygen och materialen som användes i detta examensarbete. Mjukvara som användes för design av munstycket var Solidedge vilket är ett Cad program med solid modelling förmåga. Mastercam användes för att göra verktygsbanor för Haas fräsen och även för att bestämma parametrarna för ingreppen.
Redskap som användes var Haas fräsen, en manuell borr och en metall såg.
Delen framställdes i Arcada genom CNC bearbetning i plast labbet.
Munstycket fungerade som det skulle och möjliggjorde produktion av tråd med rätt dimensioner för 3D skrivaren.

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DEGREE THESIS	
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Abstract:

The purpose of this thesis was to investigate the possibility of manufacturing filament for the Minifactory 3D printer in the Arcada plastics lab and if so how to do it and what materials could be used for filament. The main objective for the thesis was to achieve acceptable filament for the 3D printer.

This Thesis is about the process of designing and manufacturing an extrusion die for the Arcada plastics lab.

The thesis covers a broad range of manufacturing processes and design aspects during the different stages of manufacturing. The focus of the manufacturing processes lies on milling and drilling.

Topics that the thesis tackles are design issues of extrusion dies and overcoming issues with compatibility with extruder mounts with limited tools.

Manufacturing and designing of the extrusion die was done at Arcada.

Arcada provided all the tools and raw materials required the part to be manufactured.

Design software used in the thesis was Solidedge and Mastercam. The Solidedge software was used to achieve preliminary designs while Mastercam was used to finalize and generate toolpaths for the Haas Milling machine.

The die was manufactured by CNC machining on the Haas milling machine located at Arcada plastics lab. Some other machines like a manually operated drill and a sawing arm were also used when machining the part.

The die worked as designed and was able to produce filament with the correct dimensions for the 3D printer.

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FÖRORD / FOREWORD

I want to thank everyone who helped me with my thesis. Special thanks to Simo-Pekka Toivonen, Erland Nyroth and Mirja Andersson.

1 INTRODUCTION

For a long time 3D printing has been an expensive alternative for creating prototypes. However, in recent years, advances have been made and the technology has been pushed forward. Now consumer grade 3D printers are available even for people at home and schools. The main advantages of 3D printing are rapid prototyping, lesser material costs and waste this translates directly to cheaper operating cost for companies. [1]

Buying filament for 3D printing will be costly in the long run and generate a lot of waste material. So to reduce waste and decrease operating costs Arcada University of applied sciences has decided to recycle old plastic to new filament.

Recycling plastic to filament has many challenges mainly getting the filament to be the correct size and shape. Other challenges could be that recycled plastic might have the wrong viscosity or that the filament edge would be too rough. These factors are all problematic for 3D printers that use fused deposition molding (FDM) as the filament might get stuck in the printer nozzle if the viscosity is too high or because rough a surface.

This thesis is a documentation of the design and manufacturing of an Extrusion die. The purpose of the extrusion die is to extrude high quality filament for the 3D printer at Arcada plastics lab. The thesis covers the theory and a detailed documentation of the steps taken to design and manufacture the part.

1.1 Aims and objectives

The main aim for the thesis was to investigate the possibility of producing filament for the 3D printer at the Arcada plastics lab from different kinds of plastics and to test if it was possible to recycle used filament.

To achieve these objectives an extrusion die had to be both designed and manufactured successfully. Designing the die would require investigating the tolerances allowed for filament and extrusion methods of the filaments.

After this the die would have to be manufactured which meant researching the proper machining aspects of the part and possible redesigning to allow for efficient and precise machining.

Finally, the extrusion die would be tested to determine durability of the design and to examine if the extruded plastic could be produced to the correct dimension required for the (FDM) 3D printer located at the Arcada plastics lab.

The main goals for the thesis:

- investigating possibility of extruding filament
- Researching methods of achieving acceptable filament
- design and manufacture of the extrusion die
- testing the extrusion die to determine if the design was successful and usable

The thesis also gives basic understanding of common tools and methods used to achieve these goals.

1.2 Methods

Design and manufacture was mainly done at Arcada University of applied sciences plastics lab in Helsinki.
Manufacturing processes of filament were reviewed and data about tools and machinery were available at the lab was collected.
Firstly, a solid design was achieved based on the theory obtained from literature about profile extrusion.
Then the die was manufactured and finally the thesis was written.

1.3 Restrictions

Restrictions considered during this project were tools, machinery and software available. Another thing to consider was how to minimize material costs for production. Other things considered were compatibility of the die with the existing mounting system for the extruder.

2 LITERATURE REVIEW

2.1 Computer aided design

Computer aided design (Cad) is a tool widely used by design engineers. Cad is software that allows for easy modification and analysis of drawings this increases design speed. As all files are stored in, electronic form they can easily be exported to other software for more detailed analysis or used as a template for computer aided manufacturing software (Cam). [2]

> “The object is represented by its geometric model in three dimensions (X, Y and Z).
>
> The mathematical representation reduces creation of views like orthographic, isometric, axonometric or perspective projections into simple viewing transformations.
>
> Though the size of the screen is limited, there is no need to scale the drawings. Drawings can be made very accurate.
>
> The geometric models can be represented in color and can be viewed from any angle.
>
> Sections can be automatically created.
>
> The associativity ensures that any change made in one of the related views will automatically reflect in other views.
>
> Revision and revision control are easy.
>
> Drawings (geometric models) can be modified easily.
>
> More important than all, drawings can be reused conveniently.
>
> Storage and retrieval of drawings are easy.” [2]

2.1.1 Solid modelling

Solid modelling starts by drawing 2D sketches of the object. Solid modelling software then allows the user to protrude these sketches into 3D objects that can be modified to the correct shape by tools available in the software. Solid modelling is a more advanced method of Cad that allows computer-assisted calculations to achieve desired shapes. Another advantage of solid modelling over traditional Cad is the ability for real-time

rendering of the 3D object from different angles, which gives the designer a three dimensional view while designing the product.
Solid modelling is widely used in conjunction with Cam software as finished 3D objects can easily be stored and exported into Cam software. [2]

2.2 Computer aided manufacturing

Computer aided manufacturing (Cam) allows for design of toolpaths and selection of appropriate tools and setting the correct parameters for the tools used.
Cam is used to simulate the manufacturing of a part. This improves manufacturing speed and reduces waste materials as simulations can be made until the correct tools and settings are found to manufacture the part. Cam is widely used with CNC machining as it improves quality and as computers are extremely efficient at repetitive tasks. [2]

2.2.1 Computer numerical control machining (CNC)

Is computer assisted machining that can be used with a large number of machines.
The main advantages of (CNC) are faster and more accurate machining this translates directly to an overall more economical solution than traditional manual labor.
Machines that take advantage of (CNC) technology use a sensor to detect edges of the piece machined referred to as the stock. The sensor can be either mechanical or a laser. The laser sensor is more accurate than its mechanical counterpart is but both yield good results. The mechanical sensor operates by sensing pressure from the edge of the piece.
The edges are used as zero points in an X, Y, Z coordinate system so that the machine can relate the coordinates to match those of Cam software. Cam software is used to generate a G-code, which is machine code for the different types of CNC machines. The G-code contains the toolpaths, tool changes and machining parameters. [2]

2.2.2 G-code

Is a universal coding language used in machining also referred to as RS-274D. This code contains X, Y and Z coordinates for the machine with the proper speed and feed rates for the tool. When a CNC machine executes G-code it systematically does as the code instructs. It finds the location where material is to be removed selects the correct plunge rate and spindle speed for material removal and then follows the coded toolpath until it is done. The machine executes the code until a tool change is required. When the next tool has been installed, the machine continues with the next toolpath for the following tool this procedure is done until the whole program has been executed. [3]

2.3 Machining operations

2.3.1 Milling

Milling is a process, which involves removing material from a stock piece. This is achieved by cutting away material with a rotating tool. There are various shapes and sizes of these tools. The Tool itself consists of a certain number of teeth, which are responsible for the material removal.

Milling is done in several cuts as the cutters are under tremendous stress and heat up during the cutting operation. Coolant is used to combat tool fatigue.

A normal feed per tooth for a milling cutter is often no more than 0,25mm per tooth. The material removal will still be significant as it scales with the number of teeth the tool has available.

Even though the feed rate is kept low and the cutting times are kept to a minimum these tools a subject to mechanical and thermal fatigue.

Common milling tools used is the Face, End and the Ball mill.

The Face mill is a tool used to remove a lot of material fast. This cutter is generally used to create a plain stock in the right dimensions to be further milled to the correct shape by other tools. While the end mill is a tool that is capable of milling in all directions which makes it ideal for milling contours and shapes.

The Ball end mill is a special milling tool, which is good for creating rounded surfaces but not suited for cutting operations that require milling in all directions. [4]

2.3.2 Drilling

Drilling is the process of removing material by vertically pushing a drill tip into a material and simultaneously removing the chips generated by the drilling operation. A drill has two flutes designed to remove chips as efficiently as possible. At the end of the drill, there are two edges responsible for material removal.

The most common types of drills are the center drill and the counterbore.

Center drills are used to drill a small beginning for the hole to be drilled so that the counterbore centers at the correct place. This method gives more precise results than drilling without a center drill. [4]

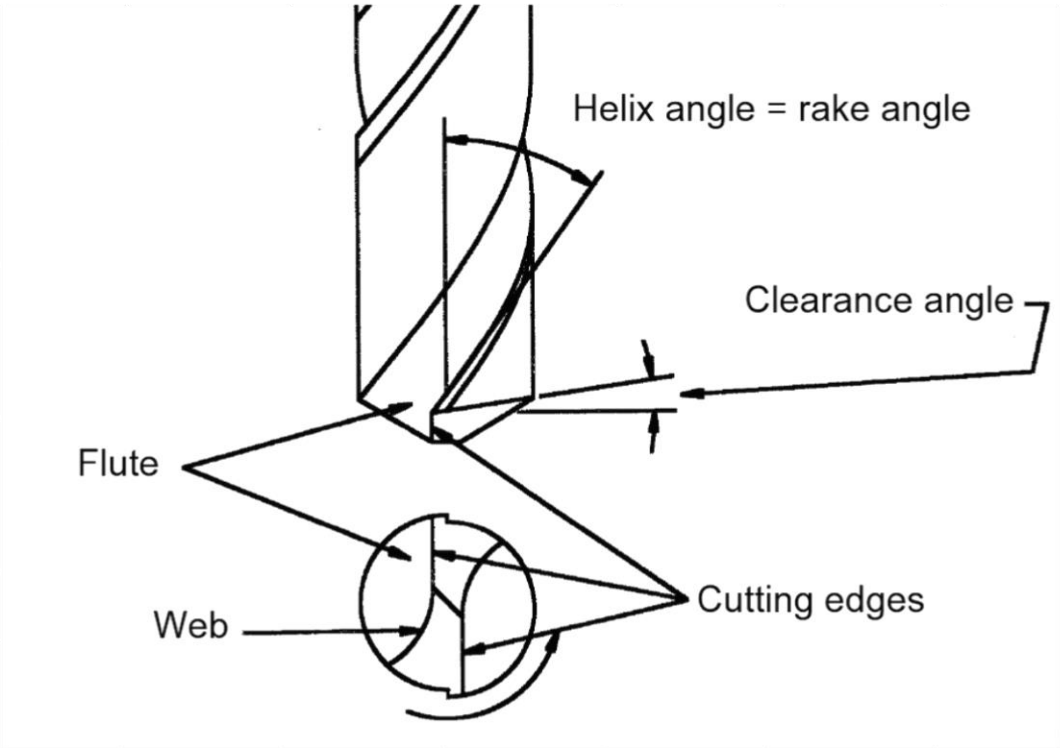

Figure 1 Drill tip [4]

2.3.3 Tool materials

The most common tool materials used for cutters are Carbide, High-speed steel, and Carbon steel. High-speed steel and carbide are the more modern and expensive tool materials, which are capable of faster cutting speeds and higher material removal rates than the traditional Carbon steel cutters. The main difference in these materials is the material used to inhibit the metal structure from becoming more ductile. The Carbon steel uses carbon to gain its structure while HSS tools use a combination of alloys in conjunction with carbon to gain its superior structure. Carbide cutters have a higher hardness and are stiffer than HSS but on the downside are more expensive as the manufacturing of these cutters is more complex. Common materials used for these cutters are tungsten and carbon. [4]

2.3.4 Calculating speeds and feeds

Obtaining the correct parameters when machining different materials is important as this ensures safe operation and optimal machining speed.

The feed rate and material removal rate are dependent on the tools used and the material to be machined. Different tool size, type and material all contribute to the amount of material that can be removed.

The feed rate is the amount of material pushed against the cutter. This can be calculated by the following formula **[vf= (z*N)*(fz)]** where z is the number of teeth, N is the spindle speed and fz feed per tooth in mm/tooth. [5]

Table 1 Feed rate

Feed rate		
Vf	**172**	**Feed rate mm/min**
Fz	0.03	Feed per tooth in mm/ tooth
Z	2	Number of teeth
N	2862	RPM

When calculating the feed rate it is important to consider what tools are being used as this can have a huge impact. Most High speed Steel cutters are able to cut aluminum with depth of cut 0,3mm with a feed per tooth of 0.02-0.03mm feed per tooth/mm tooth. [5]

To obtain the spindle speed the following formula is applied

[N= (vc*1000)/ (π*d)] where Vc is the cutting speed and d is the diameter of the tool. The reference value when machining aluminum is 90m/min. These values provided guidelines when setting the tool parameters. [6]

Table 2 Spindle speed

Spindle speed		
N	**2862**	**RPM**
Vc	90	m/min
D	10	Tool diameter
1000	1000	
Π	3.145	

Several calculations were made with various tool sizes to achieve a number that would be safe and efficient when machining the part. As can be seen from the table the spindle speed has been calculated with a tool diameter of 10mm. When smaller tools are used the material removal rate vc has to be lowered to get a reasonable spindle speed.

To calculate the Cutting speed a modified version of the previous equation can be used: **[vc= N*π*d/1000]**. [6]

2.4 Extrusion

Extrusion is the process in which material is mixed to a homogenous melt and extruded to a specific profile.

The process takes place in a cylinder that houses a rotating screw. Heaters are used in conjunction with the screw to generate the hot melt. A typical extrusion line usually involves:

- Extruder
- Cooling system to obtain final dimensions
- Pulling mechanism that pulls the profile at a linear velocity

Extrusion is a process commonly used by the plastics industry to generate products of high quality at high speed. However, these two things are in conflict as the quality degrades when production speed is increased.
To achieve good extrusion results the optimal speed for acceptable quality is desired as this will generate the highest profit. [7]

2.4.1 Extruder

The Extruder itself is a machine that consists of the following components

- Hopper
- Heater bands
- Rotating screw
- Filter plate and a die
- Engine

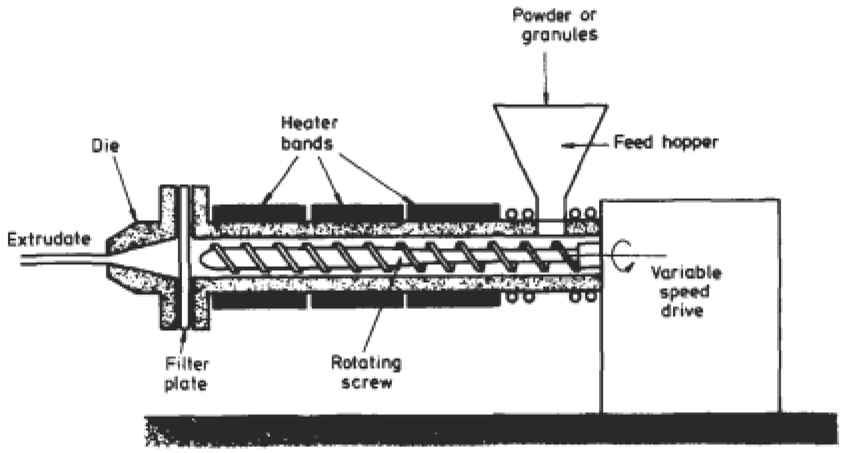

Figure 2 Extruder [8]

Granules are the raw material for an extrusion unit. These are fed through the hopper that is located above the extrusion unit. The granule is then melted and pushed forward through various zones in the screw. Finally, the melt is pushed through the extrusion die to achieve desired shape.
An extrusion unit has three zones with different purposes for optimal extrusion results.

The first zone is called the feed zone the purpose of this zone is to preheat the plastic and move it to the following zones. Design of this zone is an important aspect of extruders, as it has to supply the optimal amount of material to the metering zone not too much or too little, as the capabilities of the metering zone are limited. If fed too much material the metering zone will be overwhelmed and too little, it will starve.

In the compression zone the screw depth is gradually decreased which results in generation of pressure inside the screw. The purpose of this is to squeeze out trapped air from the plastic back to the feed zone. The compression zone is also responsible for improved heat transfer as the material thickness decreases.

In the metering zone, screw depth is constant but lesser than in the feed zone. This zone is responsible for homogenizing the melt and delivering a constant supply rate of melt with uniform temperature and pressure. [8]

2.4.2 Issues of extrusion tools

The design of extrusion tools is somewhat tricky as the behavior during flow of plastic is somewhat difficult to predict this is why many extrusion dies mainly rely on stretching to the desired cross section.

To ensure a good result the profile needs to cool down with a fast uniform rate. This ensures proper morphology in the material. This is usually done by air or water-cooling.

Other limitations set on extrusion tools that make use of stretching of material are stress on the polymer itself. The polymer needs to withstand both the thermal stress and physical stresses. [7]

2.4.3 Profile die Design

There are three main types of profile die designs. The complexity of the product to extrude determines which one of these is the best choice.

The most simple is the plate die system, which quickly changes the melt from the circular extruder opening to the desired shape. This is the cheapest and simplest design of an extrusion die. The main drawback of this design is that it promotes hot spots in the die that cause problems with thermally sensitive polymers.

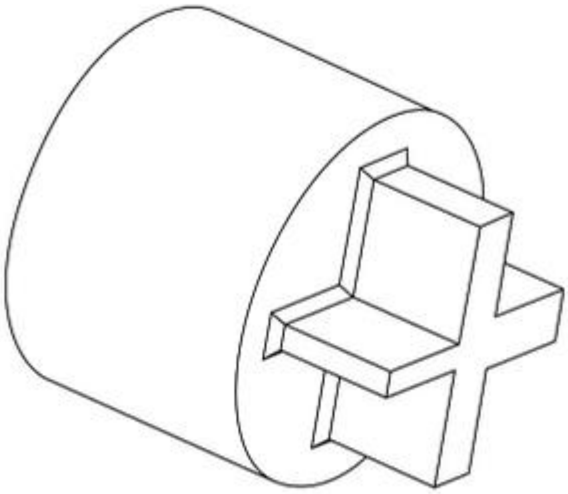

Figure 3 Plate die [7]

The second design is the Stepped die where geometry is slowly transformed with multiple plate dies which makes the progression of the polymer somewhat more discrete and generates a better flow than the plate die system. Theses dies have limited performance and used for simple profiles.

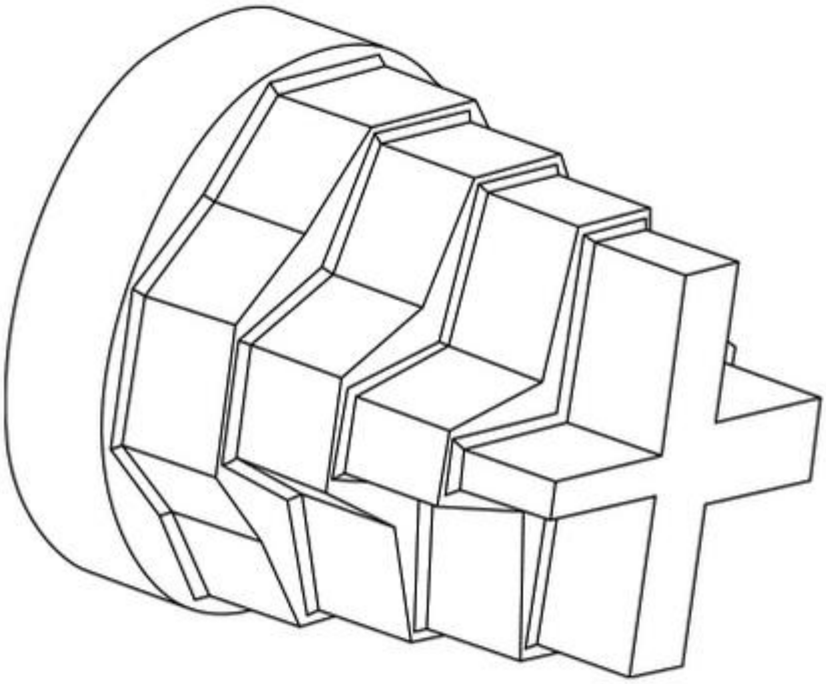

Figure 4 Stepped die [7]

The most expensive of the three is the streamlined die as it consists of many different plates to achieve optimal flow. Every plate that this die consists of is different. The purpose of this is to slowly progress towards the desired shape smoothly. These dies are used for the most demanding extrusion applications.

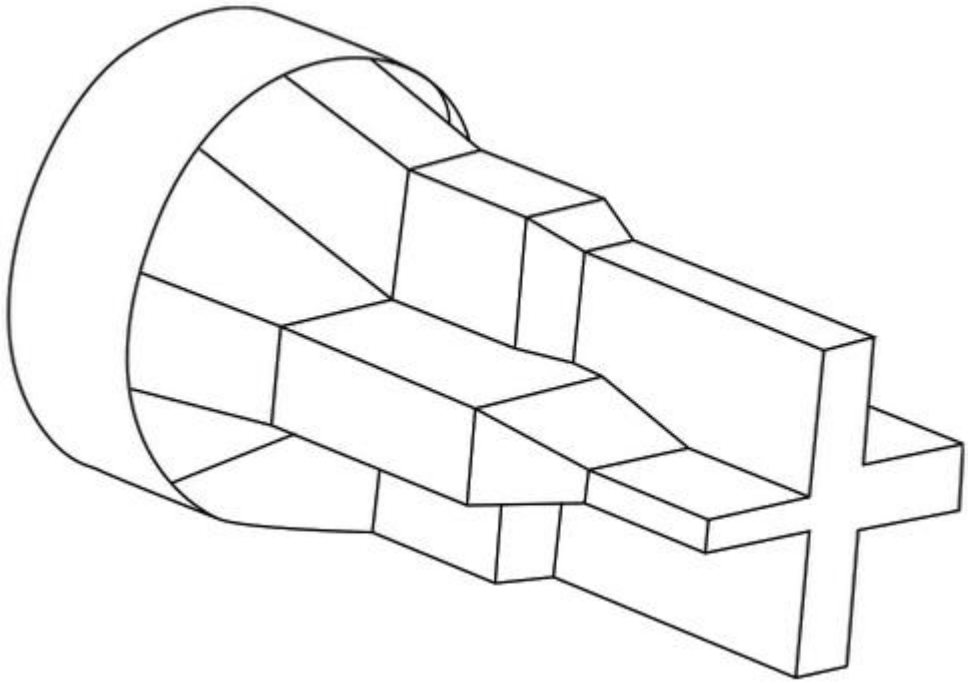

Figure 5 Streamlined die [7]

The streamlined Die consists of the following zones:

- Adapter zone this plate is responsible for connecting the die to the extruder and is fully circular.
- Transition zone is the plate that connects directly to the adapter plate and the pre- parallel zone. As shown in figure 6 the geometry of the part is quite simple however depending on the product to be extruded this part can be very complex
- Pre-parallel zone is a zone that starts restricting flow as the plastic is forced towards the desired shape.
- Parallel zone is the final zone of this type of die. The material is forced to its final shape in this plate. This zone has a constant cross section, which ensures uniform flow rate. This part is also responsible for a pressure drop as the main purpose of this design is to reduce deformations generated upstream.

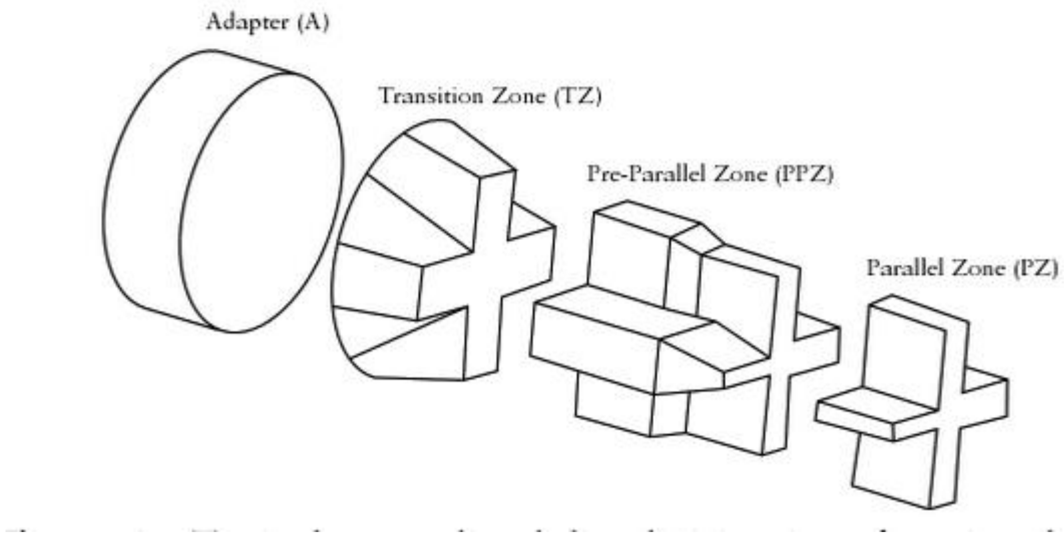

Figure 6 Streamlined die plates [7]

The main tasks to achieve when designing extrusion dies are to achieve a smooth transition of polymer and successfully enable manufacturing of the desired shape. Minimizing internal stress and to avoid rheological defects and thermal degradation. [7]

2.5 Fused deposition molding (FDM)

Fused deposition molding is a process based on extrusion. Consumer grade 3D printers commonly use this process. These printers use filament of either 1,75mm or 3mm in diameter. [9]

The process starts by loading a computer program with the desired profile. Then a toolpath is created for the nozzle by software much like the CAM software. The profile is then generated by dropping material layer by layer on top of each other until the product is complete by following the toolpath. Thermoplastics like ABS and PLA are most commonly used as filament. The plastic is heated and melted in the nozzle from its solid form.

3D printing is mainly used for rapid prototyping, as it is a considerable cheaper process compared to subtractive alternatives like CNC machining. [10]

2.6 Plastics

Plastics are categorized into three main group's thermosets, thermoplastics and elastomers.

Thermoplastics are heat sensitive plastics as the bonds between the polymer chains that contain covalent bonds are weak and heat sensitive. These polymers generally contain carbon and are made by addition or condensation polymerization.

Thermoplastics are commonly used in regular everyday applications such as drinking bottles.

As these polymers melt at high temperature and solidify when cooled, they can be recycled easily.

Thermosets are plastics that have cross-linked chains. The polymer is chemically linked. This makes the material heat resistant, as the cross-linked polymers will resist movement. These plastics are achieved by condensation polymerization. Thermosets are generally considered superior to thermoplastics in engineering applications as they have stronger material properties. The drawback of these materials is that they are hard to recycle.

Elastomers are polymers that are slightly cross-linked which give them the unique ability to stretch when under stress and return to their original shape. Elastomers have long polymer chains as this is part of the requirements of elasticity. The stress required for an elastomer to deform is very low. [11]

2.6.1 Acrylonitrilebutadiene styrene (ABS)

ABS is a thermoplastic polymer commonly used by the plastics industry for different applications. It is one of the most common materials used for consumer grade 3D printer filament. ABS is a hard and sturdy material with a long lifespan, which makes it ideal for mechanical applications. [12]

Typical processing temperatures range from 215-250°C. [9]

2.6.2 Polylactic Acid (PLA)

PLA is also a common material used by consumer grade FDM 3D printers. It does not require a heated surface for printing. The material is generally weaker than ABS. However, this material is environmentally friendly as it is biodegradable. [12]
The processing temperature is lower and ranges from 160-220°C. [9]

2.7 Software and machinery used

Siemens Solid edge was used for preliminary design of the extrusion die.
The Cam software used was Mastercam X6. Both these programs are common design tools used by engineers all over the world.
Machines used:

- W-HAAS CNC machine
- Vammas W-Dr drill
- Kastro W-saw pivot arm

Figure 7 Haas milling machine [13]

Figure 8 W-Dr drill [13]

Figure 9 W-saw [13]

All machinery, tools, software and raw materials were provided by Arcada University of applied sciences.

3 DESIGNING AND MANUFACTURING

3.1 Design

The extrusion die preliminary designs were achieved by consulting with Simo Pekka Toivonen lab engineer at Arcada and by reviewing data about extrusion of filament. This led to a design of an extrusion die that would achieve the desired filament diameter by stretching. This meant leaving the output diameter larger than the desired filament diameter. The reason for designing it this way was partly that the smallest milling cutter available would not have been small enough for a die that would extrude the exact dimension that was required.

Also as previously stated in the literature section it is hard to achieve and exact diameter when extruding so it is better to try and stretch the material to the desired dimensions.

Plastic flow was also considered, optimal flow would have been achieved by machining a funnel shaped structure inside the die as this would give minimal flow resistance by eliminating all corners as corners generate material fatigue and thermal degradation. This became an issue, as the tool size was restricted due to compatibility with the existing mounting system for the extruder. As the appropriate milling cutter was not available, the nozzle was redesigned.

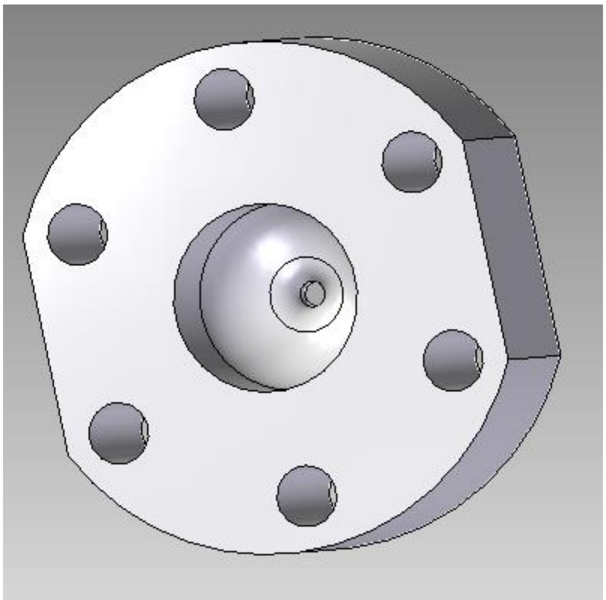

Figure 10 Solidedge design rev 1

The nozzle was now designed to a round shape instead of clean funnel.
Drawbacks with the new design were elevated pressure levels in the nozzle as there would be corners that generate flow resistance.
The mounting system was designed to be compatible with the existing hexagonal mount with the correct dimensions.
To minimize waste materials the initial single die design was redesigned to become a modular design in case of failure to achieve the desired filament dimensions and for ease of creating filament in different sizes if required in the future.
In the last design stages, a pressure ring was added on the nozzle part to make a better seal between the two parts to ensure a good flow of the plastic.

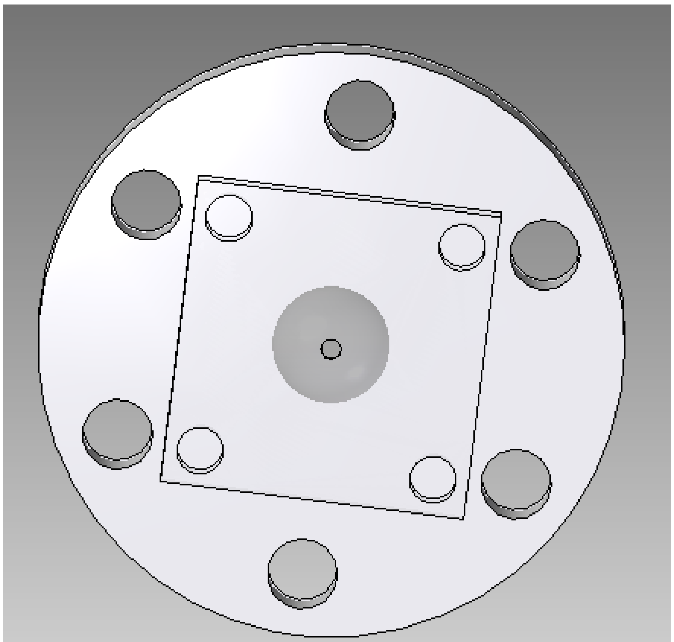

Figure 11 Solidedge design rev 2

In the final design, the roundness of the part was also removed from the mounting part as this was a purely cosmetic feature.

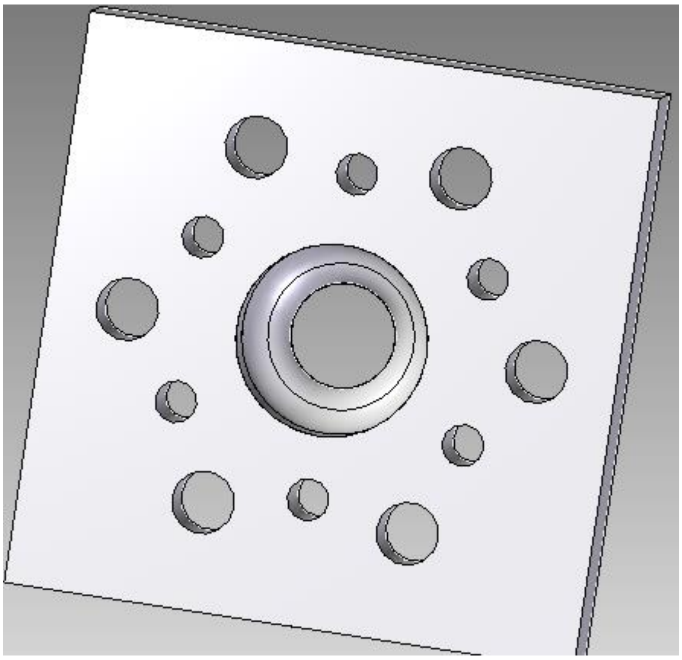

Figure 12 Solidedge Mount final

The mounting system for the nozzle was also made hexagonal to give greater structural strength as the flow could not be made optimal.

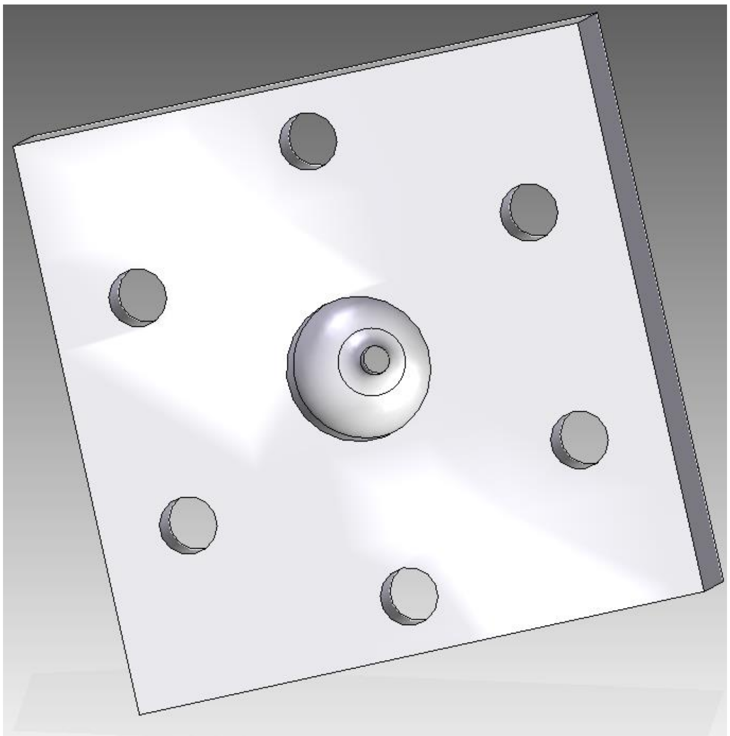

Figure 13 Solidedge Nozzle final

3.2 Toolpathing and parameters

All toolpaths were made using Mastercam and parameters for the tools were obtained by calculations made based of general speeds and feeds formulas. [5]
Consulting with Simo-Pekka toivonen and Erland Nyrothe lab engineers at Arcada led to some changes in these paramteters.
When simulating tool paths big areas were milled. Further consulting with Simo-Pekka Toivonen led to a redesign of toolpaths that generated less stress for the milling tools in use as some of the tools being used were quite small and fragile unable tolerate great stress levels.

The parts that would be milled using the End mill and Ball mill would first be drilled so that the area to mill for the milling tool would be smaller as it would only need to mill on one side at a time instead of milling in all directions.

Table 3 Tool Parameters

Tool Parameters	
Feed rate	250
Plunge rate	150
Retract rate	250
Spindle speed	2500

As can be seen from the table above the feed rate was increased from 172 to 250 mm/min as the tools used were able to handle more stress than the theoretical calculations used as guidelines let believe.

The plunge rate is the parameter that dictates how fast the cutter is moving towards the material surface while the retract rate determines the movement speed away from the surface. The spindle speed is the amount of rpm the engine is rotating the cutter.

Table 4 Material removal

Material removal	
Drill Peck	0.5mm
Depth of cuts Milling	0.3mm

3.3 Machining

3.3.1 Stock pieces

The selected material for both parts was to be aluminum alloy for tools. This special aluminum alloy designed for use when producing mold tools is more durable than regular aluminum. [14]

Dimensions required for the die mount and nozzle were 55x55x15 and 40x40x12 respectively. These pieces of aluminum alloy were obtained by measuring pieces roughly with the desired dimensions. Then cutting pieces of these blocks and finally milling the blocks obtained with a face mill to the correct dimensions getting a plain and smooth surface to work with.

3.3.2 Detailed machining operations list mount

The mounting piece would have to be milled from two sides, as the mounting bolts for the hexagonal extruder mount had to be sunk in to the die so that the nozzle part would fit on top.

First, the part was machined from the bottom side, as it was important to get and accurate midpoint so the mount would line up correctly with the existing system.

Before the machining, a simulation was run on both the bottom side and the top side on the HAAS milling machine. Then the 55x55x15 piece was attached to the Haas workbench. Once this was completed and the zero points were set on the milling machine to correspond with the ones in the g-code the program was started.

Firstly, all holes were center drilled by the 3mm center drill.

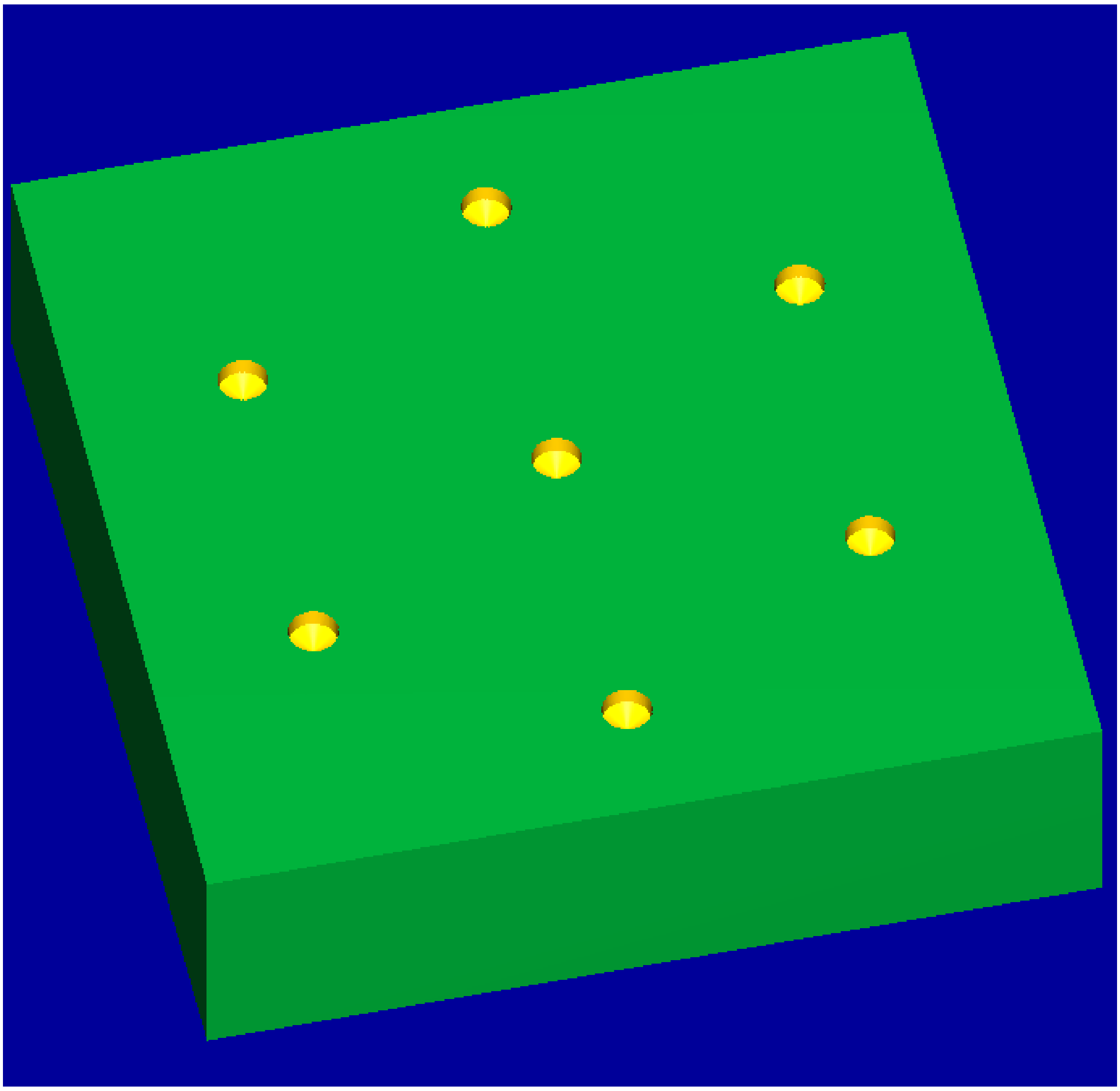

Figure 14 Mastercam

After this, the hexagonal mounting holes were drilled with the 5mm drill. A threading tool would later be used to thread the mounting holes manually.

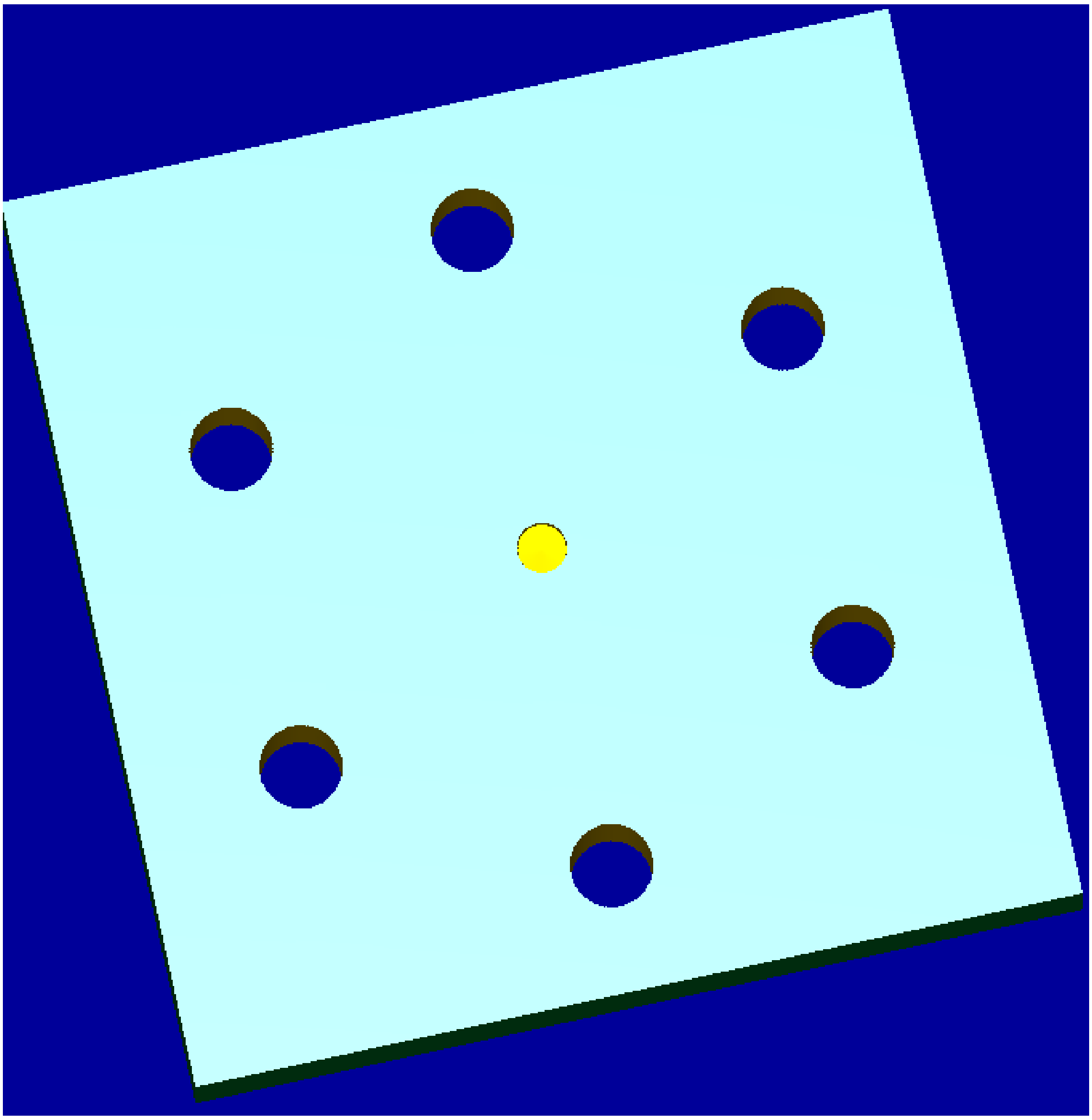

Figure 15 Mastercam

Now the 10mm drill was used to drill a hole in the middle to reduce stress on the milling cutter that would be used next.

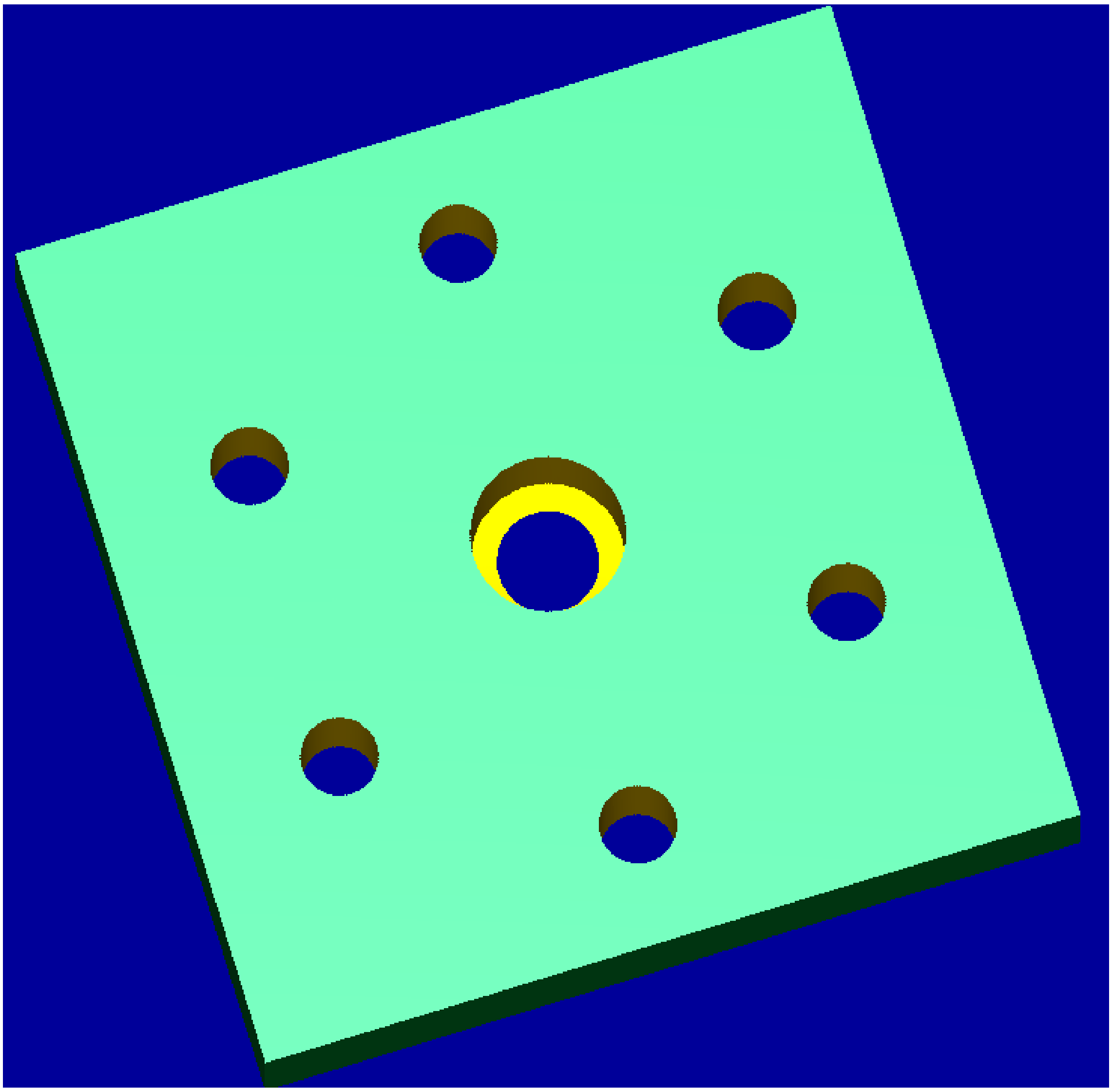

Figure 16 Mastercam

Finally, the bottom side of the mounting system was machined round by the 10mm Spherical end mill.

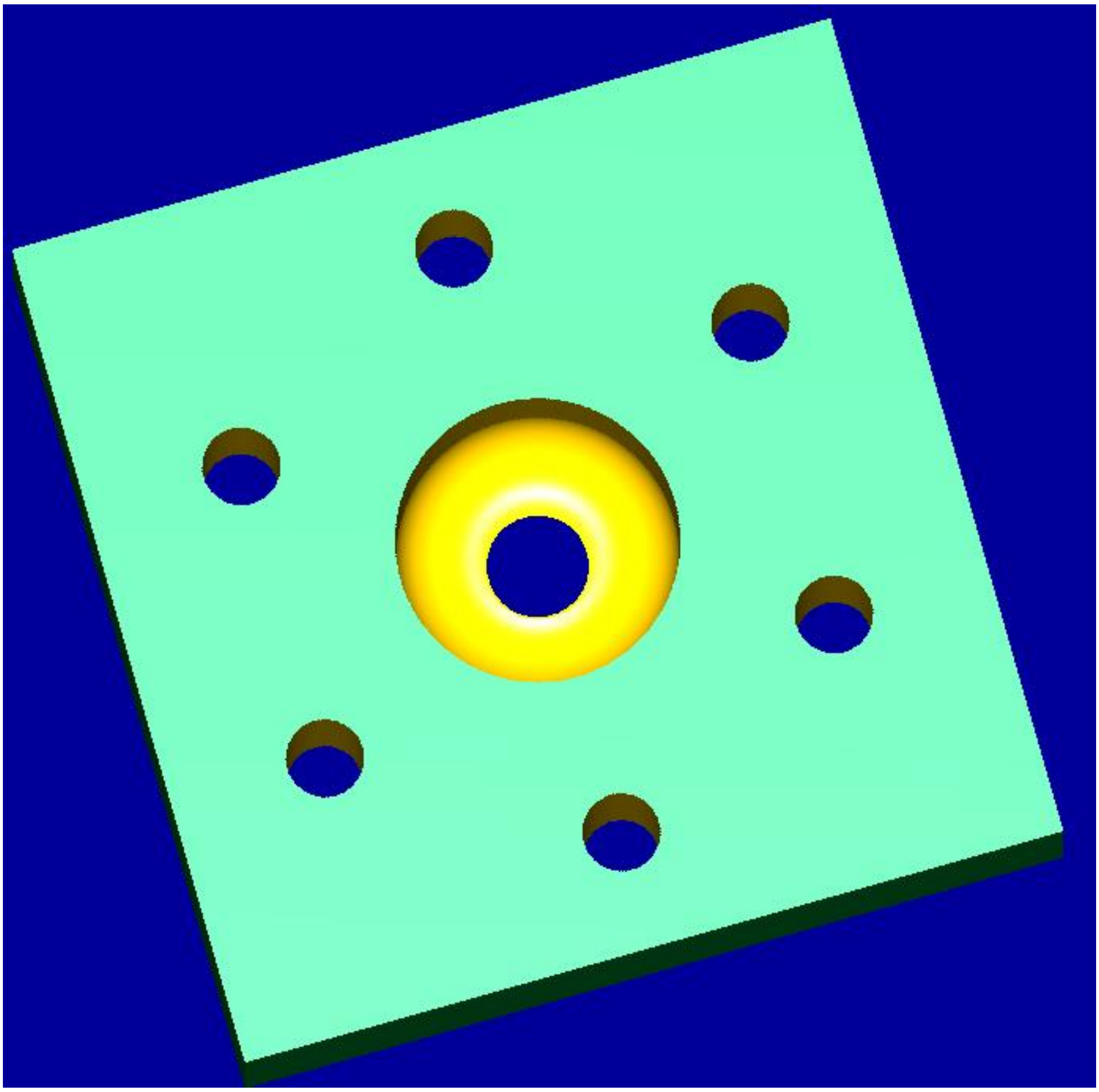

Figure 17 Mastercam

When removing the piece after the operations had finished. Some of the operations had failed. The holes were not drilled all the way through this was later corrected by manual drilling operations however this resulted in a bad finish as the drill pushes chips outward when making a hole. This was corrected by using sandpaper to make the surface reasonably smooth so the part would fit with the nozzle. Ideally, all holes should have been firstly drilled by a smaller diameter drill to reduce stress on a milling cutter and then milled to the correct dimensions to get the best result.

After the bottom side was finished the top side was milled. As it was hard to maintain precision, it was decided that the sinkholes for the bolts would be made somewhat larger than necessary to avoid incompatibility issues. The piece was reseated on the workbench top side up. After this, the g-code was loaded for the top side and the machining operations started.

Firstly, the sinkholes for the hexagonal mount were milled by the 6mm end mill.

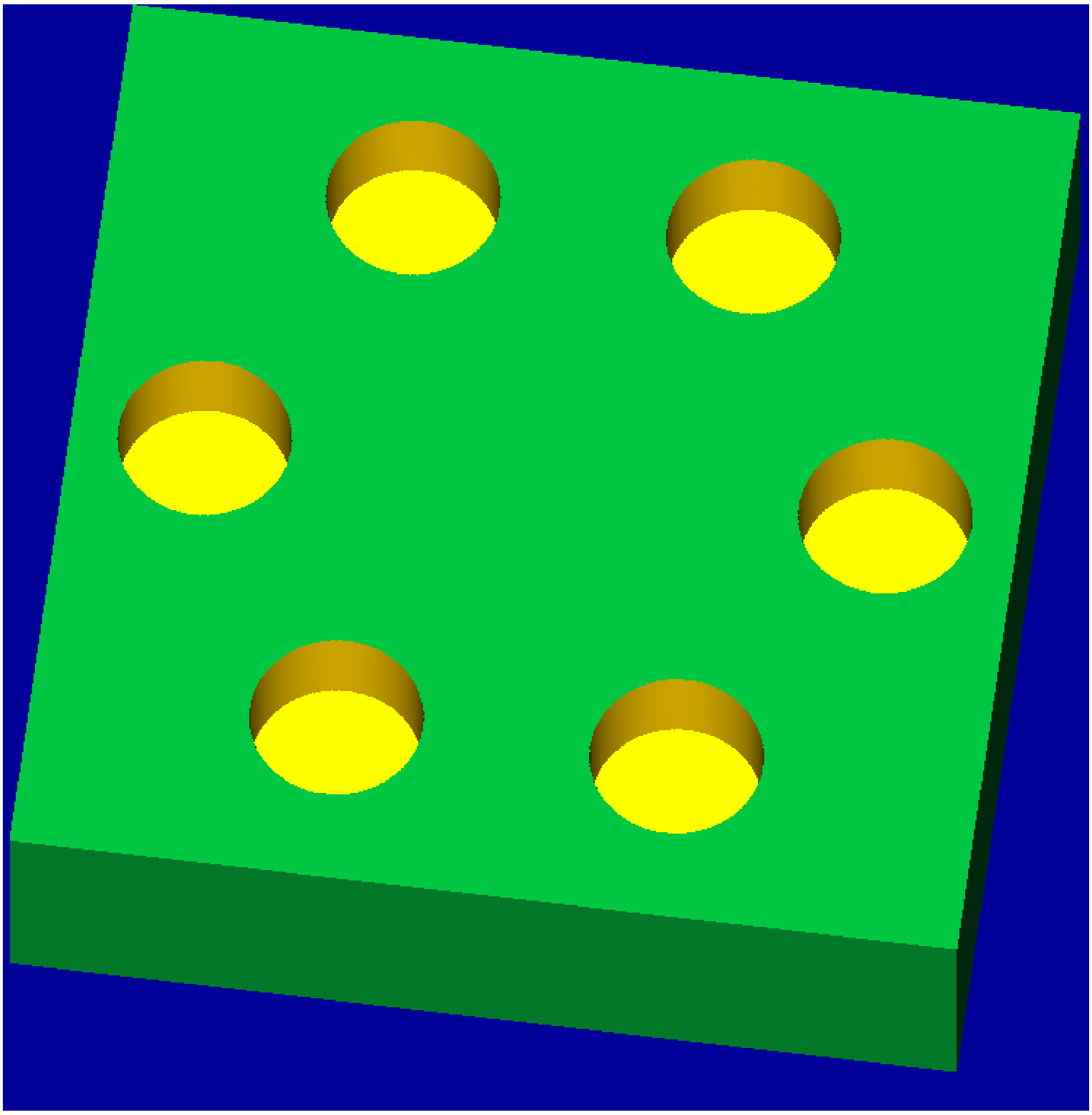

Figure 18 Mastercam

Next, the mounting holes for the nozzle were to be machined. This required the Center drill to machine small indentations for added accuracy.

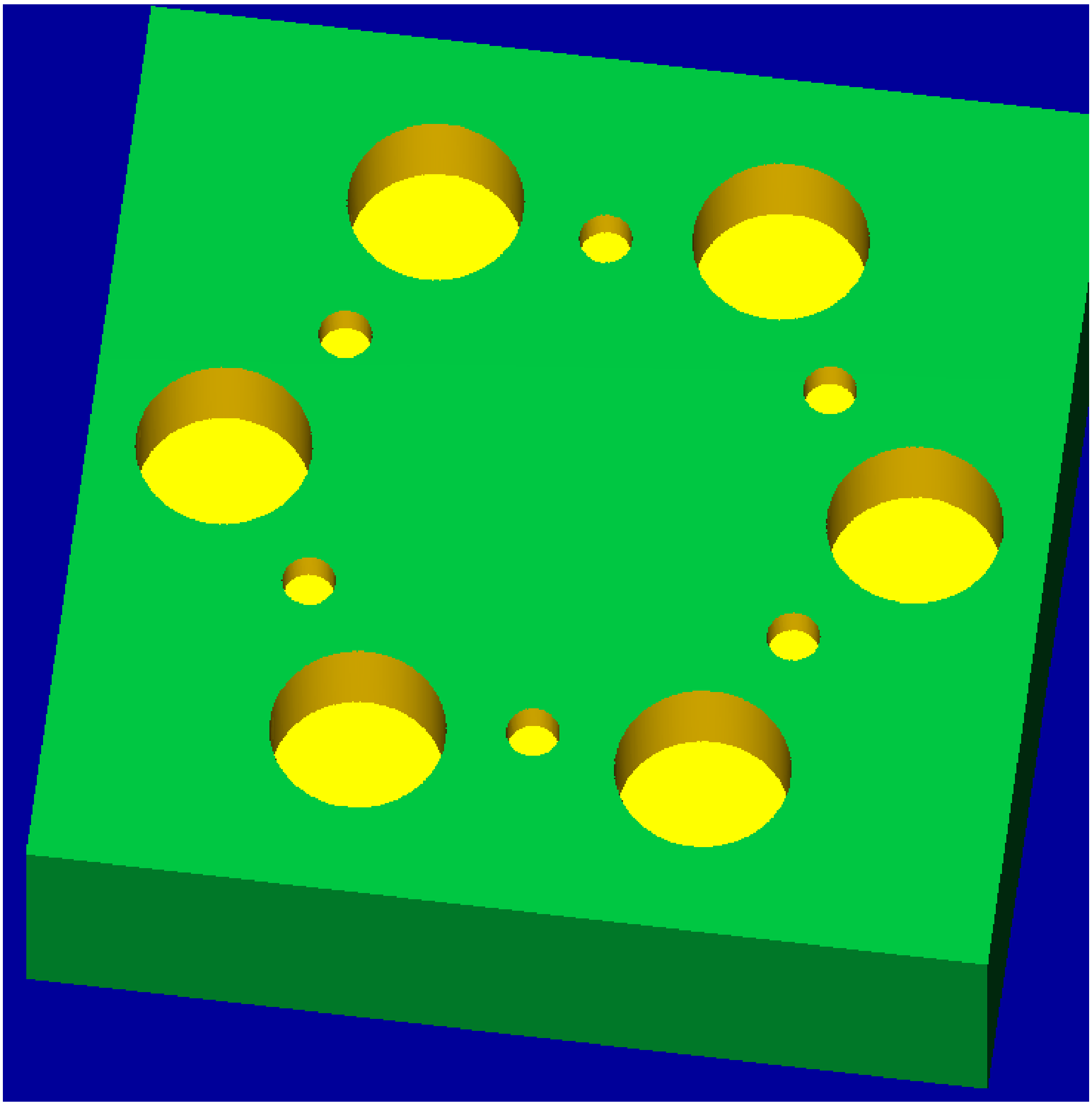

Figure 19 Mastercam

Finally, the 3,5mm mount holes were drilled. These holes were also later threaded manually.

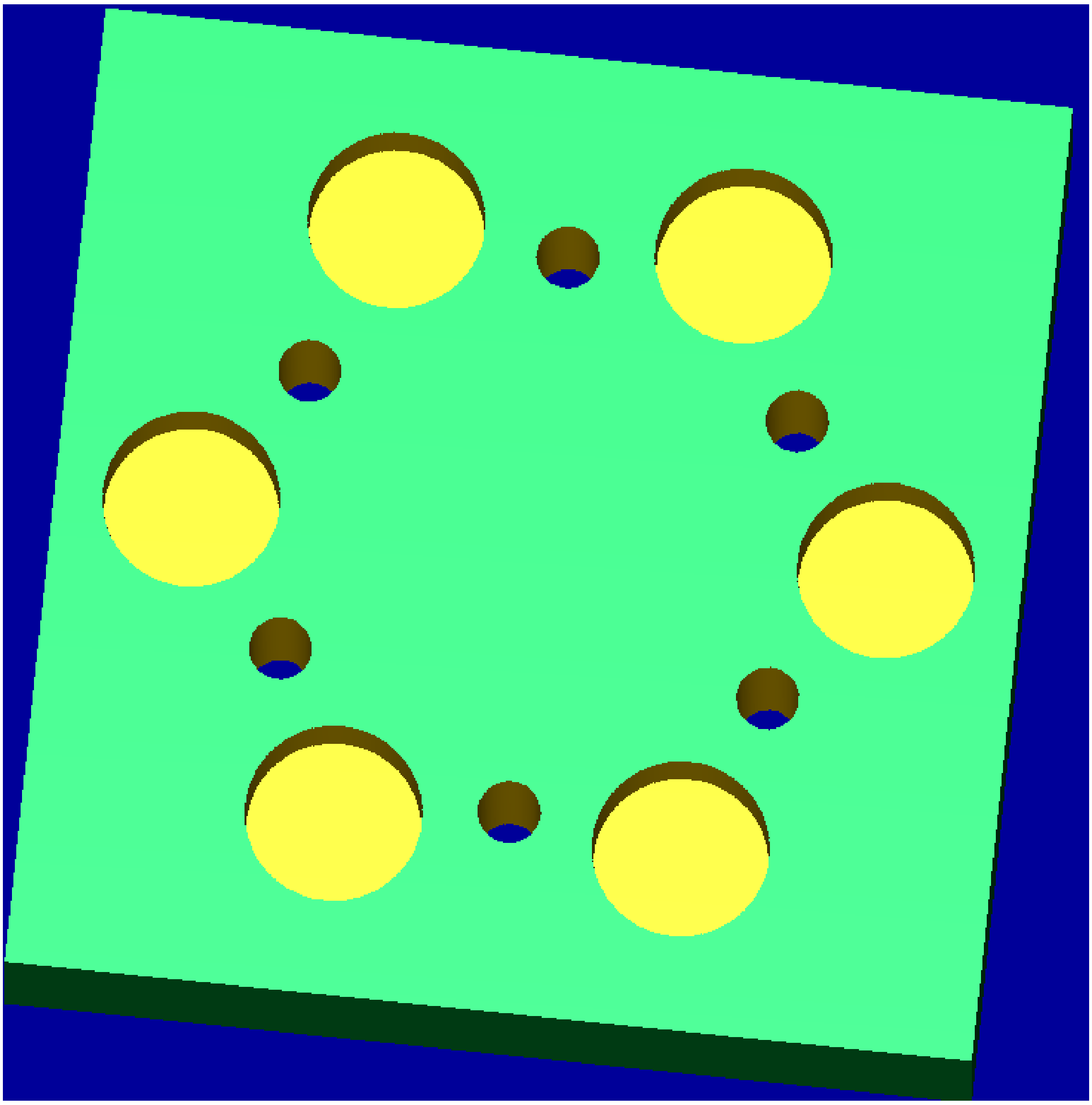

Figure 20 Mastercam

Table 5 Mount Tool list

Tool list			
Diameter	Type	Material	Teeth
3	Center drill	High speed steel	2
5	Drill	Stainless steel	2
10	Spherical End mill	High speed steel	2
6	End mill	Hard Metal	2
3.5	Drill	Stainless steel	2

3.3.3 Detailed Machining operation list Nozzle

The nozzle was also to be machined from both sides, as some features required flipping the part. As with the mounting piece, the nozzle was placed on parallels in the Haas workbench and thereafter the zero points corresponding with the g-code were set. When this was finished the simulation of the g-code was run.

Firstly, all holes that were to be made were center drilled.

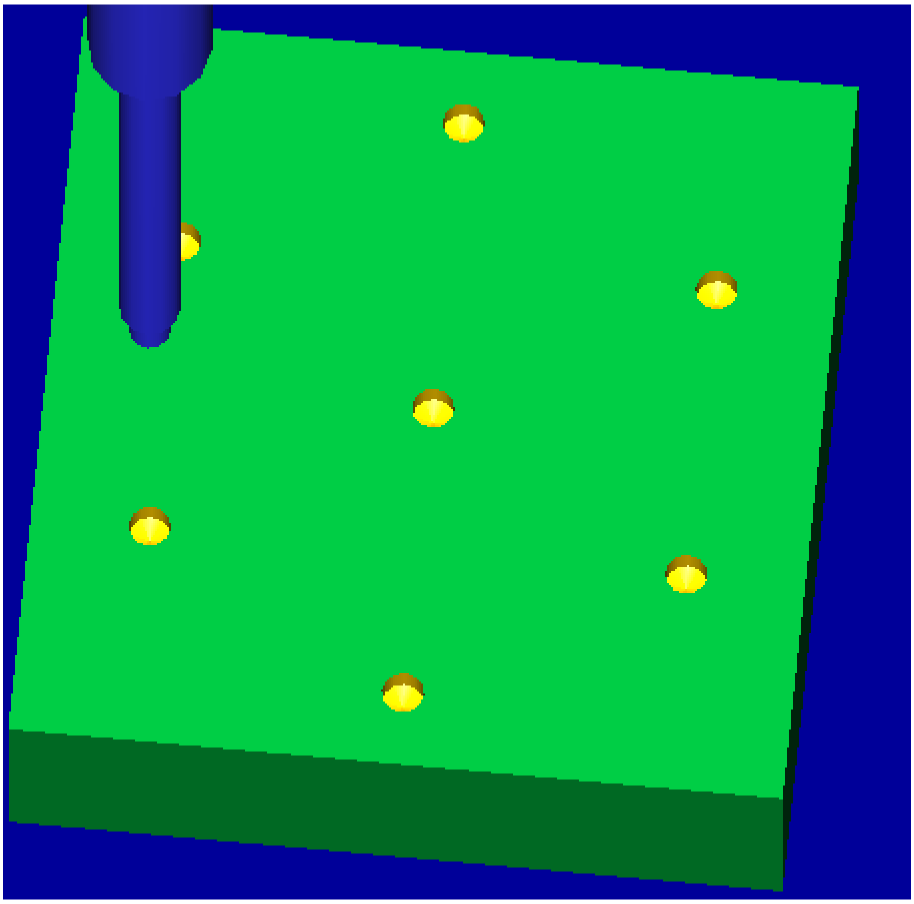

Figure 21 Mastercam

Then a 7mm drill was used with peck command to drill the inner structure of the nozzle.

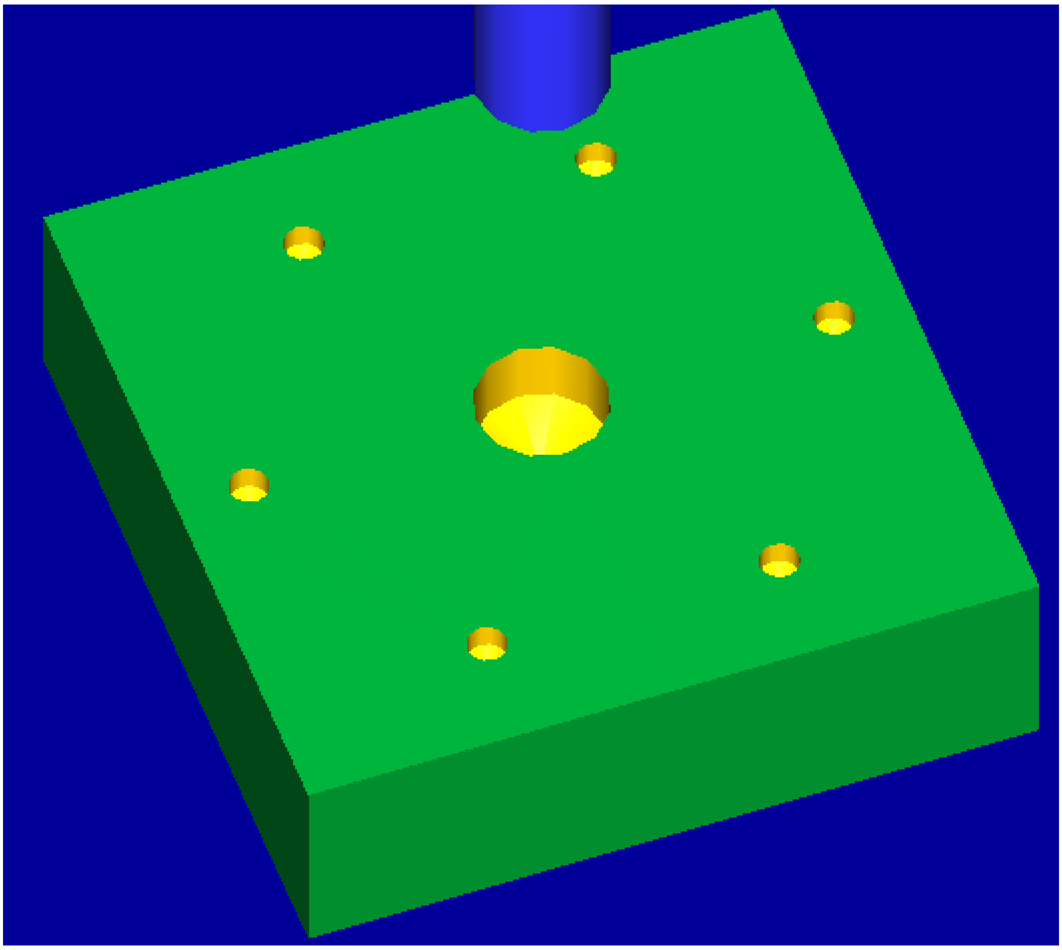

Figure 22 Mastercam

After this, the inner structure was center drilled to make a midpoint for increased accuracy.

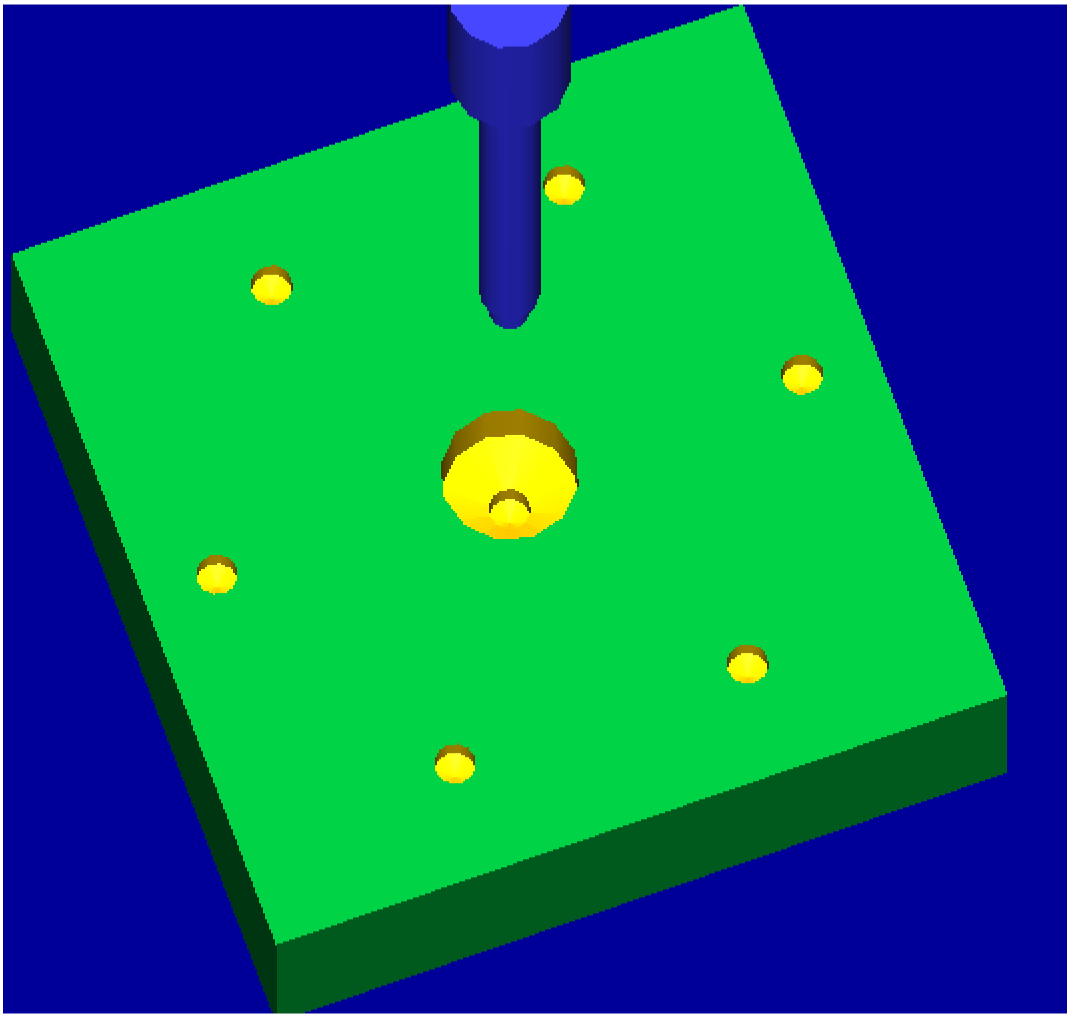

Figure 23 Mastercam

Now the extrusion output was milled by the tiny 2mm end mill. As previously stated the 2mm diameter of the extrusion output would allow for material stretching to the desired diameter by pulling.

The 2mm tunnel depth was machined to be 4mm to ensure enough pressure to build up in the nozzle so the plastic would be forced to the correct shape.

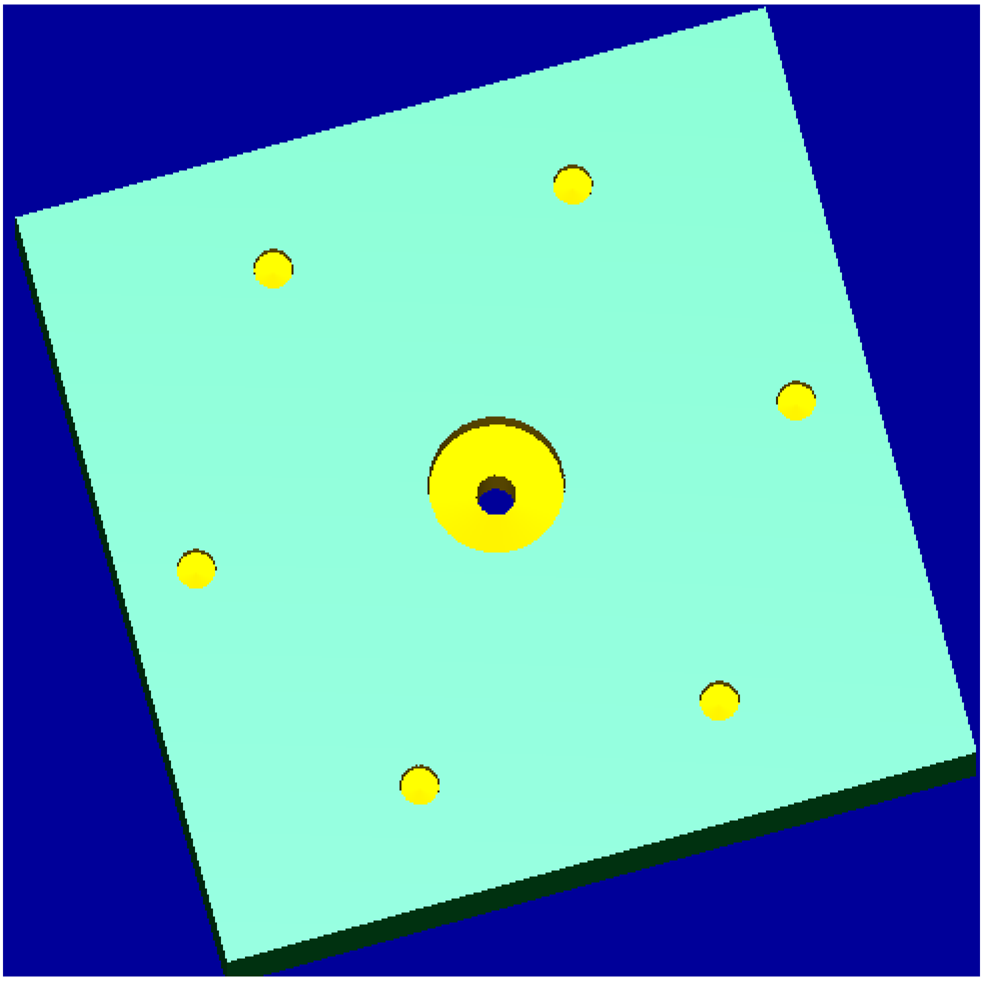

Figure 24 Mastercam

Next, a 4mm drill machined the mount holes.

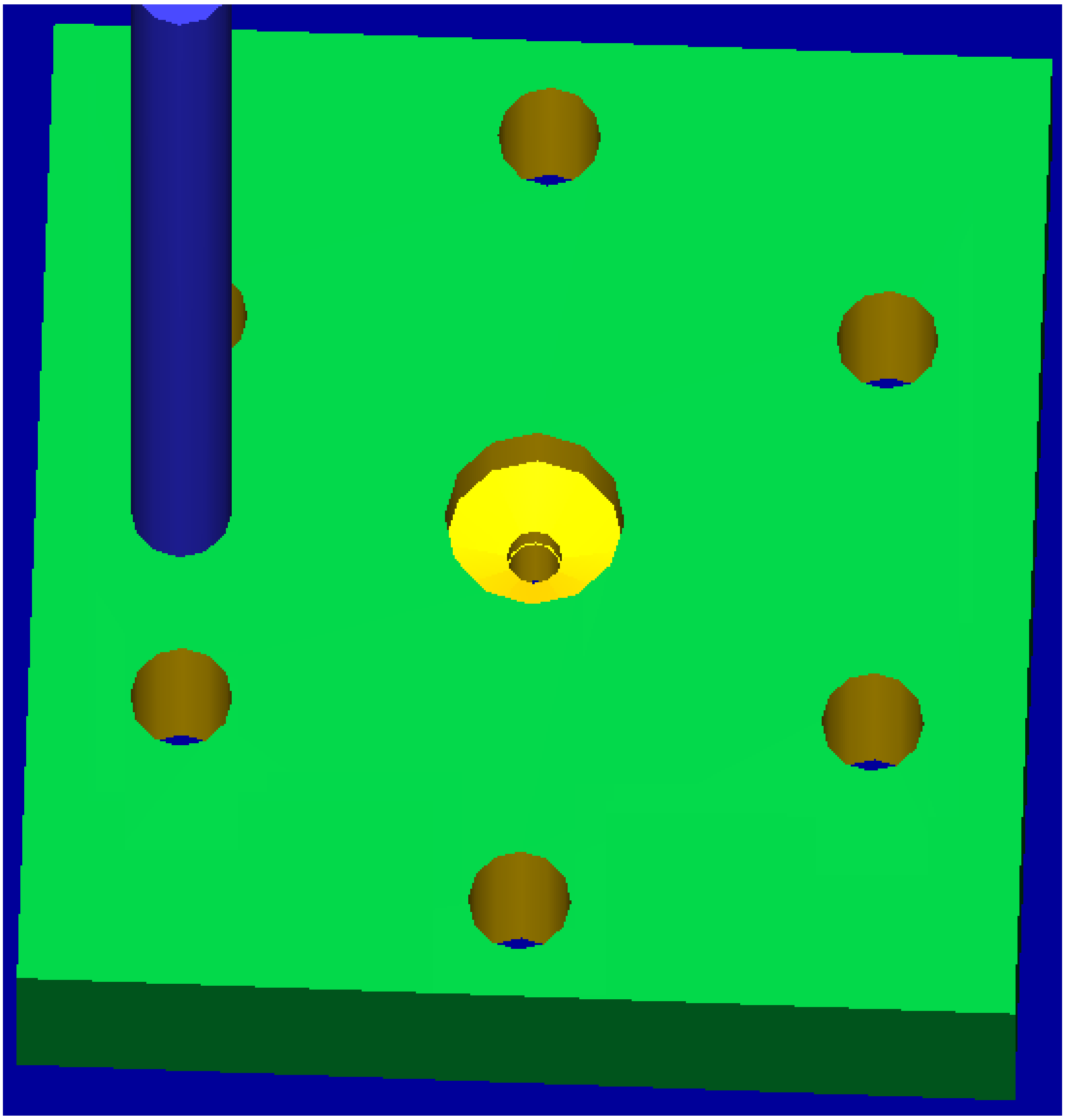

Figure 25 Mastercam

The inner structure was now ready to be milled by the 6mm spherical end mill, which resulted in a nice round shape. As previously stated the flow would not be optimal due to this shape and would generate unnecessary stress on the part.

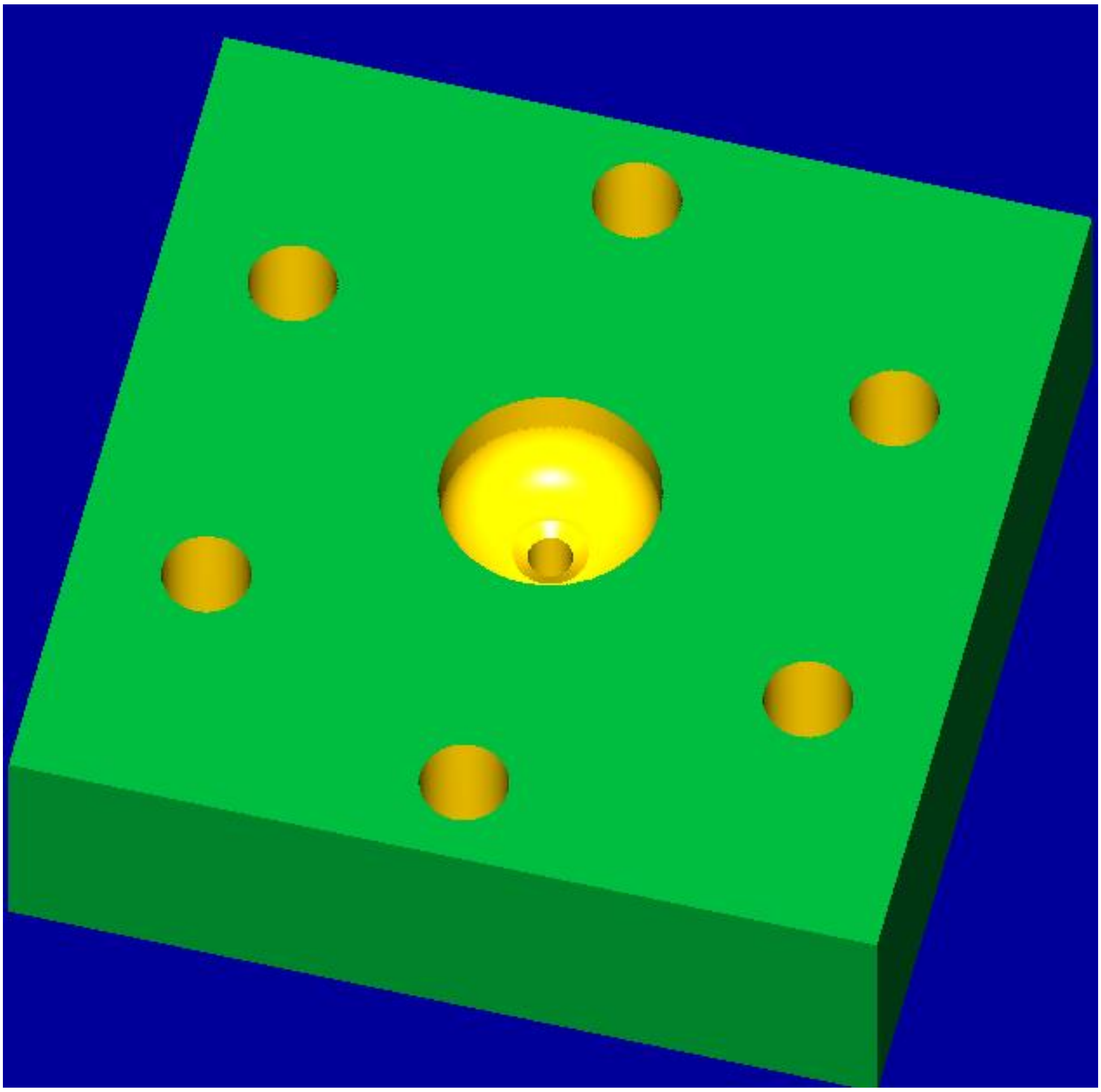

Figure 26 Mastercam

Finally, the pressure ring was machined with a 16mm end mill. The purpose of the pressure ring was to increase the pressure between the two parts to ensure a tight zeal by reducing the contact area. The pressure ring was machined to be a 2mm surface protrusion.

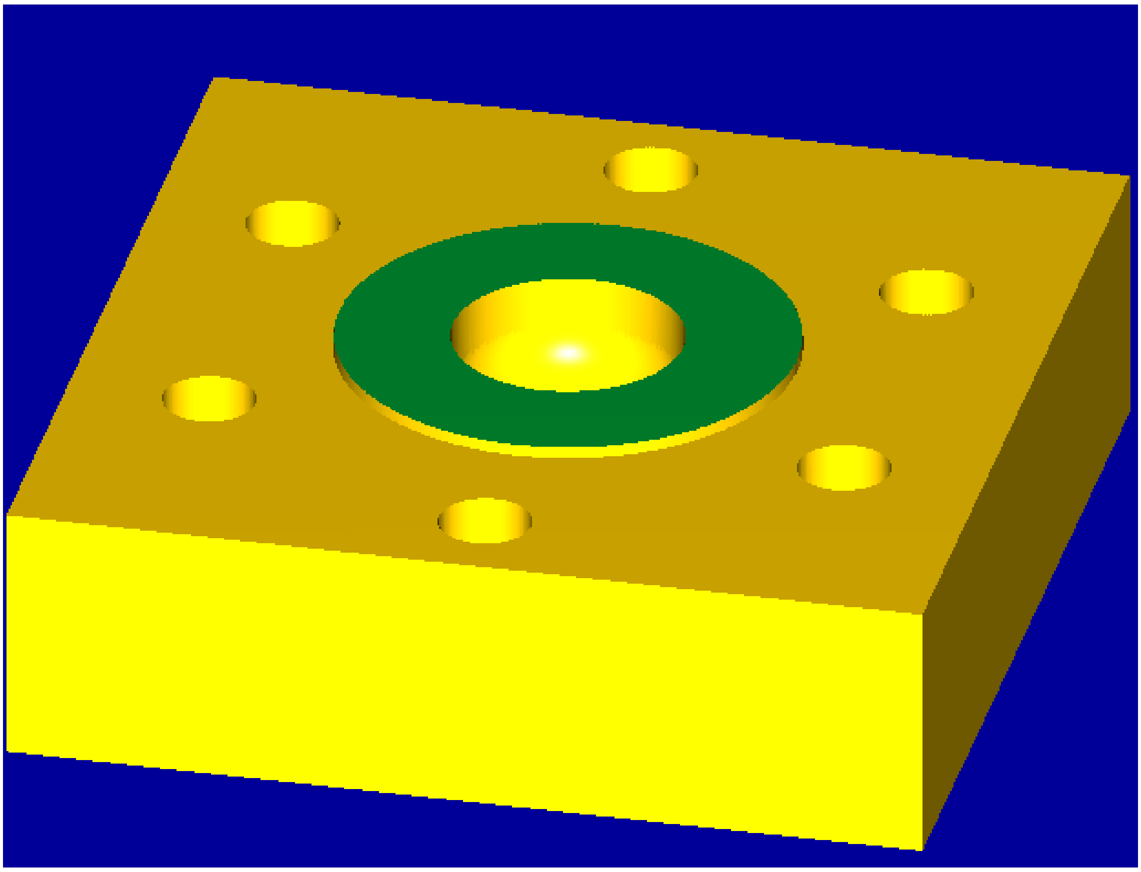

Figure 27 Mastercam

After the bottom part was machined. The part was flipped and the topside was machined.

Sinkholes for the M4 bolts were made using a 6mm end mill. The depth of the holes was 6mm.

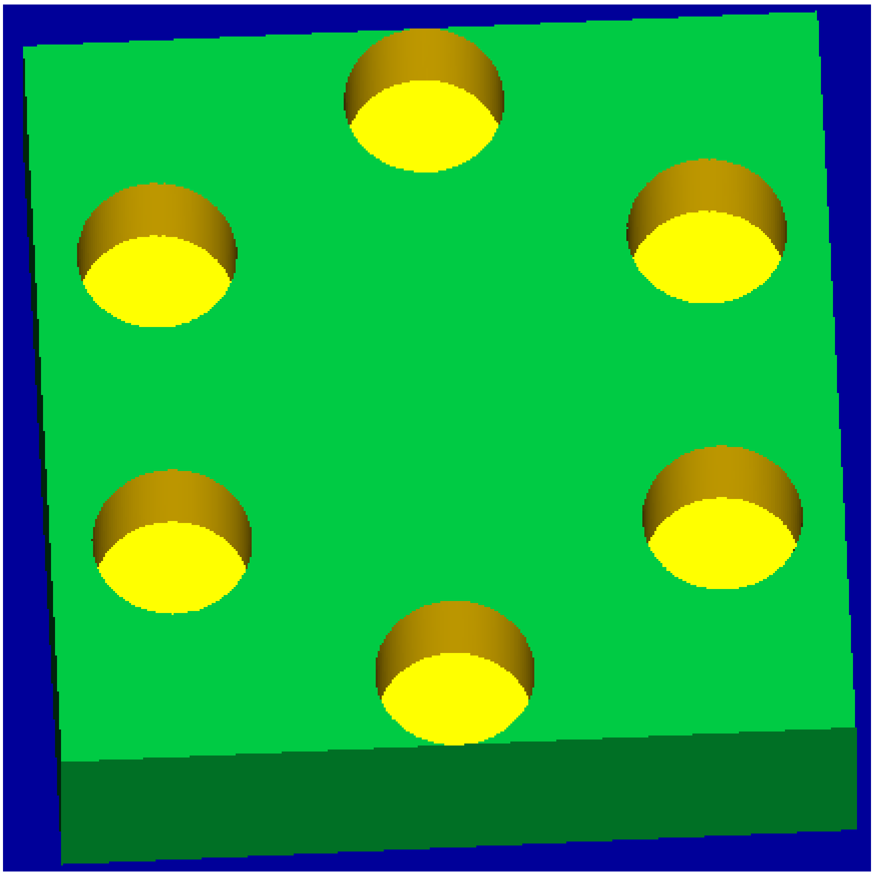

Figure 28 Mastercam

Table 6 Nozzle Tool list

Tool list			
Diameter (mm)	Type	Material	Teeth
3	Center drill	High speed steel	2
7	Drill	Stainless steel	2
4	Drill	Stainless steel	2
6	Spherical End mill	High speed Steel	2
16	End mill	High speed steel	2
6	End mill	Hard Metal	2
2	End mill	Hard Metal	2

4 DISCUSSION

Most of what was done was based on theory of design of extrusion dies. Understanding of these was essential for successfully designing a die. As stated below it is hard to translate design to an exact science as a lot of design aspects often resort to trial and error.

> ”Due to the large number of factors and restrictions involved and to the complexity of the polymer melt rheological behaviour, extrusion die design was, and still is, more an art than a science.” [7]

However the understanding of the process of generating filament and selecting the appropriate means to achieve the goals did reduce a lot of the guess work. Also the simplicity of the end product helped to achieve the goal with the first prototype even though some design aspects were changed during the process of manufacturing.

Manufacturing also required understanding of machining processes and limitations of these to successfully achieve the desired die shape. Every tool and machine had their limitations that had to be understood so the design could be made.

A great deal of precision was also required as the die consisted of two parts that had to be compatible with each other and the extruder.

5 CONCLUSION

This thesis has covered development and manufacturing of a extrusion die to achieve acceptable filament with dimensions and respective tolerance of 1,75+0,02. This was achieved by stretching as designed. The die was successful in extruding PLA, ABS and Recycled HDPE filament. Air-cooling was used to cool down the plastic and a puller unit was used to stretch the material to the desired circumference. [15]

Table 7 results [15]

Extrusion temperatures zones (^{0}C)	Extrusion speed (rpm)	Cooling method	Pulling device voltage (V)	Filament size (mm)
175	15	Room temperature	8,4	1,75+0,02

Some machining and design aspects could have been improved in the design. For instance redesigning the die with optimal flow with the cone like structure and successfully milling the part. This might improve quality of the filament however as the nozzle was properly milled the improvement would most likely be marginal at best. Higher quality tools and more accurate machining could also increase the performance of the die. As a smoother nozzle surface generates a smoother filament surface.

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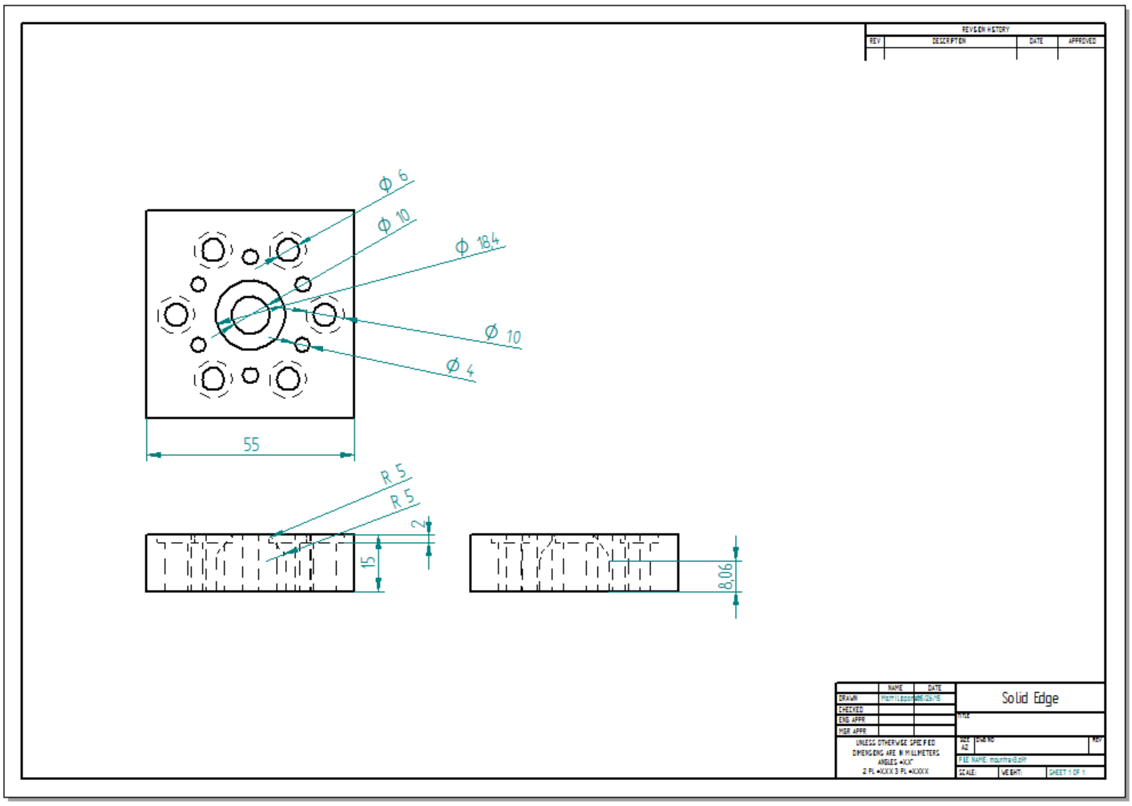
APPENDICES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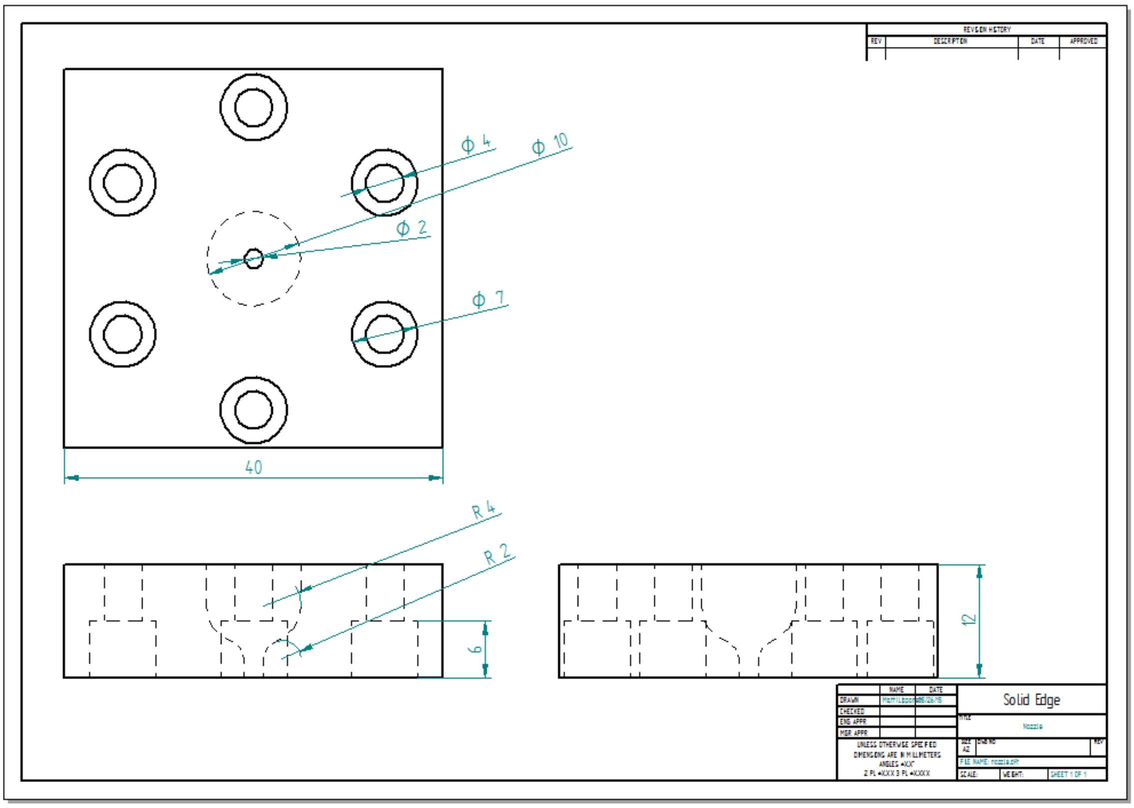
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