The Application of Rapid Prototyping Technology and FMEA quality tool in the Development of Automotive component

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Abstract

The purpose of this research is to study and apply the rapid prototyping technique using fused deposition modeling (FDM) in improving the quality of an automotive part. A machine that works under FDM principle will be used to produce the final product. An automotive component has been selected as the product for this research and application. Before continuing the fabrication of product, the critical path that must be considered is the design improvement to the target product. Failure mode effect analysis (FMEA) introduced as a tool in to improve the quality design to a better product level. The analysis from FMEA tool is translated to the design and product development. The research's findings however focus to only a selected part in automotive component. This result is inapplicable to other automotive component. Selection of material for fabrication limited to the machine availability and ability. This is the first known research that adopts a FDM machine to improve the existing product without ignoring the product functionality in real condition.

Keywords: Rapid Prototyping, fused deposition modeling, Failure mode effect analysis, automotive part

1.0 INTRODUCTION

1.1 Background of study

Rapid Prototyping (RP) refers to the layer-by-layer fabrication of 3-D physical models directly from a computer-aided design (CAD). This additive manufacturing process provides designers and engineers the capability to literally print out their ideas in the three dimensions [T. Weis et al., 2007]. Rapid prototyping is known by many terms as per the technologies involved, like SFF or solid freeform fabrication, FF or freeform fabrication, digital fabrication, AFF or automated freeform fabrication, 3D printing, solid imaging, layer-based manufacturing, laser prototyping and additive manufacturing [Brown, R., Stier, K. W. 2002]. RP processes enable to produce a model or prototypes that have the same capabilities and features with the real one. The prototypes act as a functional working model of it design and identify some of its possible pros and cons before it is actually produced. According to Chua C.K., Leong K.F., Lim C.S., 2003, the prototypes also allow the user to be involved in testing design ideas. In automotive industry, the application of RP technology has been widely employed in research and development. As for example, an automotive engineer might to design a new and more futuristic body kits for a car. Rather than just a model or prototype, RP processes can manufacture and produce the component that inherit the real product and can be tested as it real function defined after it is passing the process development and finishing process.

1.2 Statement of the problem

Perodua Kancil model car has been selected as reference and it's left back of the door outer handle as this research subject. Customers' complaints on left back outer door easily break or disfunctional.

1.3 Purpose of the study

This research will apply the RP technology and use the FMEA to upgrade or improve the part's current design. New designs of the part will be then analyze to choose which will be the best improvement of the part.

1.4 Objectives of the study

To apply RP technique using the FDM machine in improving the quality of an automotive part.

To practice FMEA as a tool in to improve the quality design to produce a better product level.

1.5 Research questions

What is the usage of RP in improving the quality of the automotive part?

What is the function of FMEA in assisting the improvement of the automotive part?

1.6 Significant of the study

This research will help to prevent and reduce the possibilities of malfunction of the current part's design in the future.

1.7 Scope of study

This research only focused on an automotive component. This result is inapplicable to other automotive component. Selection of material for fabrication limited to the machine availability and ability in the university.

2.0 LITERATURE REVIEW

2.1 Automotive Component using RP.

Development of a new product is a challenging task. The demands of the automotive industry today include not just superior quality, but also to realize a new product with a fast turnaround cycle time within the constraints of a restricted budget. Enhanced productivity and reduced cycle time can be achieved by automating the repetitive design iterations [Chua C.K., Leong K.F., Lim C.S., 2003]. By using Rapid Prototyping Techniques (RPT), car manufacturer today produce plastic parts for prototypes faster and even cheaper compared to the techniques used up to now. Prototyping for automotive applications is not limited to small parts. Multiple prototype components can be joined to create very large items. It has become a standard practice in product development. A lot of companies have own this FDM machine such as Saab General Motors, Mitsubishi, Toyota, Bentley, Wolkswagen, Nissan, and others [Mueller, D. H., Mueller, H. 2000]. The reason is Rapid Prototyping produces dimensionally accurate and highly detailed parts in durable materials that have many valuable uses to reduce product development time and costs. There are many potential applications for these parts regardless of the material and process that they are made from.

2.2 Fused Deposition Modeling

Stratasys, Inc. manufactures the Fused Deposition Modeling (FDM) systems which is one of the most popular RP techniques. By referring to Serope Kalpakjian & Schmid, S., 2006, this process is rather simple in concept and does not cure its material with a light source. The systems offered are the first truly office environment and desktop machines available. The Stratasys FDM system uses a reel or cassette of plastic filament that is fed into a heated extruding head, melting it to a temperature just above its solidification state prior to deposition. Within a heated build chamber, the machine head fills in the 2-dimensional profile of each slice in the X and Y directions on a movable build platform to form each layer as shown in Fig. 1. The material solidifies as it is placed, creating a laminate of each slice, but is kept at an optimal temperature within the build chamber to allow for fusing with the next layer. A second material, which forms the support structure for overhanging features, is also traced onto the same layer if needed. The part is then lowered by the platform to allow for the next layer to be added; repeating the process for each slice until the 3-dimensional object is completely built. Materials include ABS and medical grade ABSi; Elastomer E20 for flexible parts; and investment casting wax. Parts produced can be machined and finished and the ABS materials are quite strong and may be used in pre-production marketing units. Part detail and quality are very good, but fine details and sharp edges lose some definition. The ability to hold tolerances across the entire part is in the range of +/-.005.

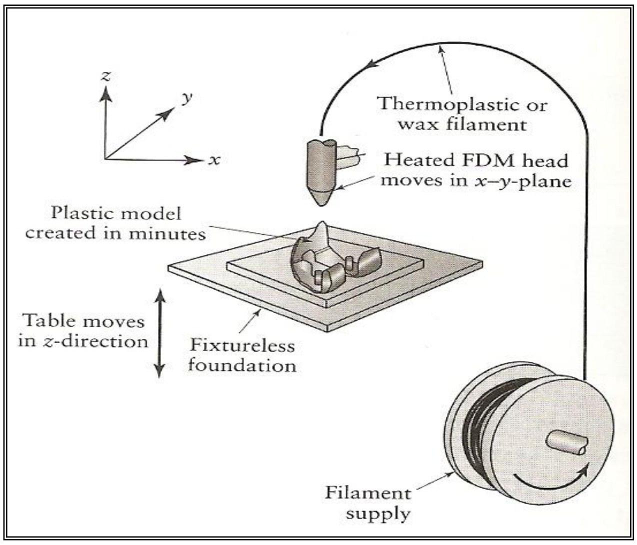


Fig. 1: Schematic diagram of FDM [Kalpakjian & Schmid, 2006]

Once the part has finished its successive layers and the build is complete, the part is removed from the FDM. The supports of the part should break away easily from the completed model. After the supports have been removed successfully, the completed model is sanded to enhance surface finish.

2.3 Failure Mode Effect Analysis

FMEAs were formally introduced in the late 1940's with the introduction of the military standard 1629. Used for Aerospace / rocket development, the FMEA and the more detailed Failure Mode and Effects Criticality Analysis (FMECA) were helpful in avoiding errors on small sample sizes of costly rocket technology. The primary push for failure prevention came during the 1960's while developing the technology for placing a man on the moon. Ford Motor Company introduced FMEA to automotive in the late 1970's for safety and regulatory consideration after the disastrous "Pinto" affair. Ford Motor Company also used FMEAs effectively for production improvement as well as design improvement [Palady, P., 1998]. FMEA is a team-based methodology for identifying potential problems with new or existing designs. It is one of the most frequently used hazard-analysis tools. FMEA identifies the mode of failure of every component in a system and determines the effect on the system of each potential failure [Stamatis, D.H., 1995].

According to George E. Dieter, Linda C. Schmidt, Failure Modes and Effects Analysis (FMEA) is methodology for analyzing potential reliability problems early in the development cycle where it is easier to take actions to overcome these issues, thereby enhancing reliability through design. FMEA is used to identify potential failure modes, determine their effect on the operation of the product, and identify actions to mitigate the failures. A crucial step is anticipating what might go wrong with a product. While anticipating every failure mode is not possible, the development team should formulate as extensive a list of potential failure modes as possible. The early and consistent use of FMEAs in the design process allows the engineer to design out failures and produce reliable, safe, and customer pleasing products. FMEAs also capture historical information for use in future product improvement [G.E. Dieter, L.C. Schmidt, 2008].

2.3.1 Types of FMEA

There are several types of FMEA's; some are used much more often than others. FMEAs should always be done whenever failures would mean potential harm or injury to the user of the end item being designed. The types of FMEA are [M.P.Goover,et al, 2008]:

- System - focuses on global system functions
- Design - focuses on components and subsystems
- Process - focuses on manufacturing and assembly processes
- Service - focuses on service functions
- Software - focuses on software functions

3.0 METHODOLOGY

This research was conducted throughout these procedures:

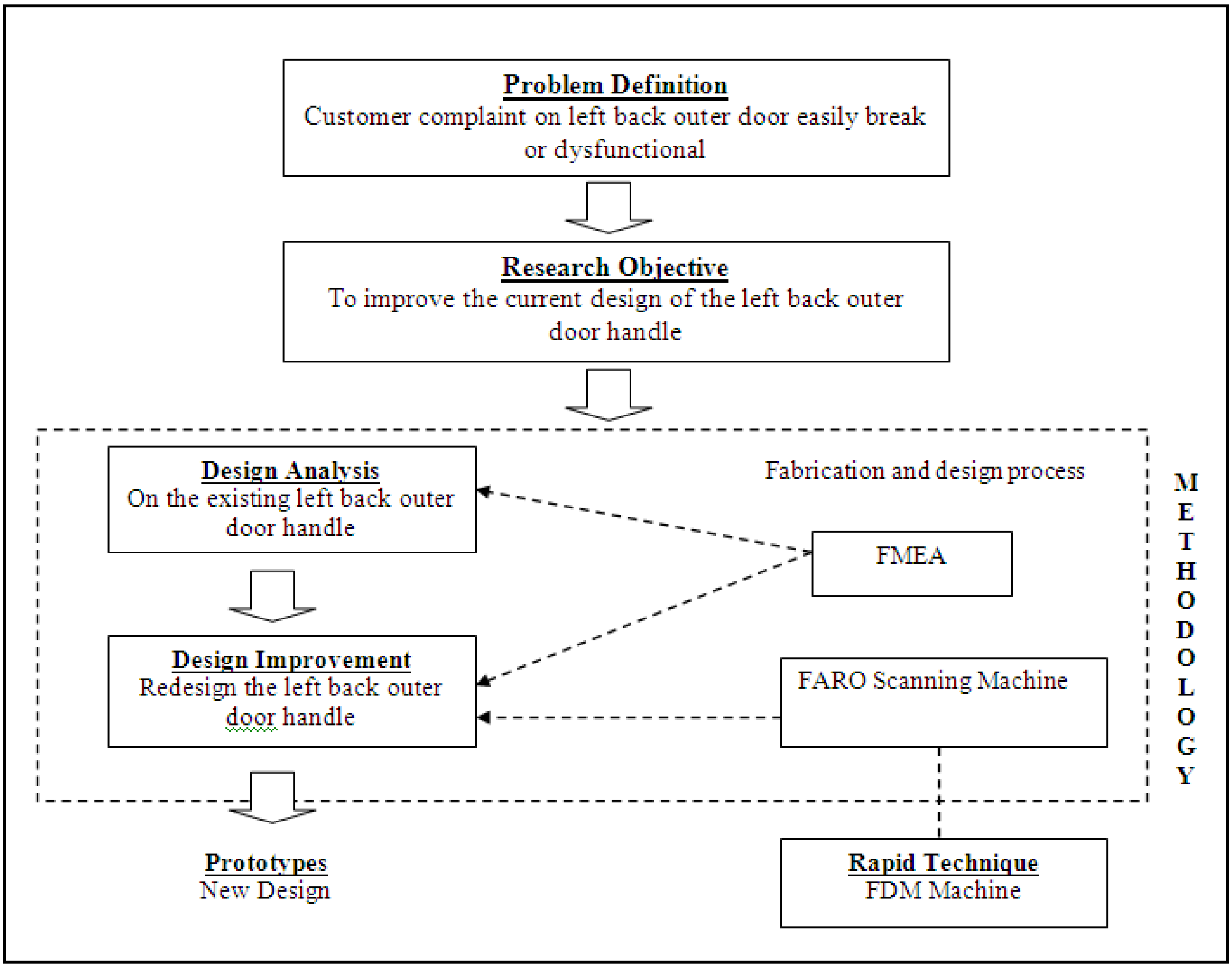


Fig. 2: Research Methodology

3.1 Design Analysis

The original part was analyzed and each component in the part was taken into consideration. Hence, the part can be described as the following figures:

Fig. 3: Original Model of outer handle back left door of Perodua Kancil car model

From the original part, there were only several parts being chosen as research subject due to the fact that these parts were the most easily damaged part in the original design. Thus, in this research the part that being taken into considerations was as followed:

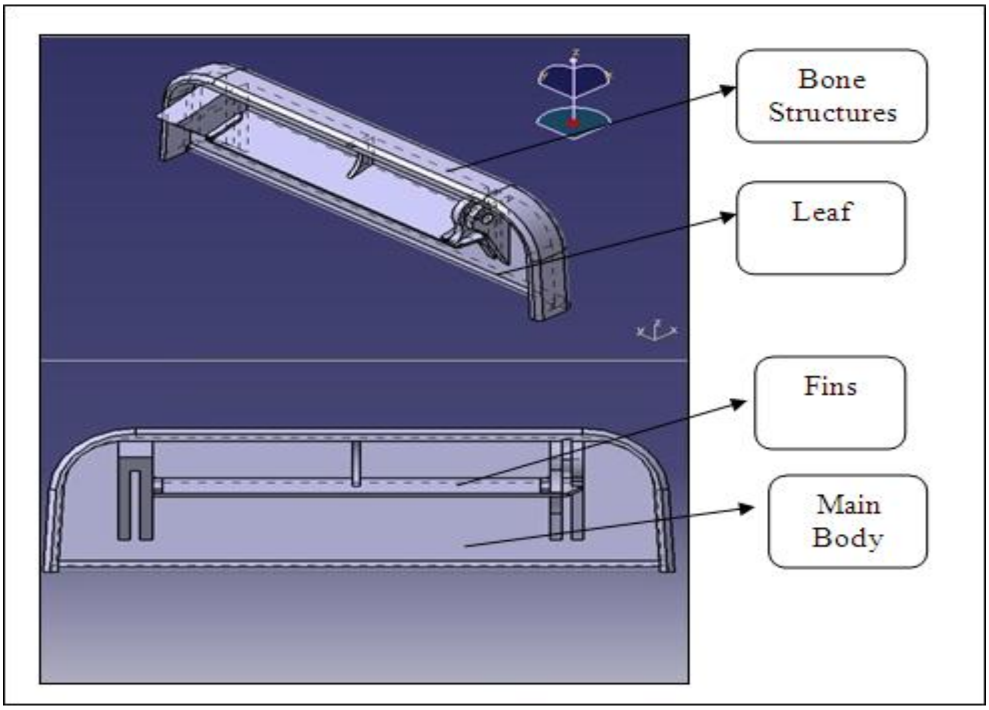


Fig. 4: Diagram description of the part chosen.

Description of parts:

Fins

Part made of a thin part layer plate that separate the mechanical system of the handle from the user's hand. It also avoid from any injuries. Original part usually has very soft fins and improves in term of flexibility compared to the spare-part component.

Main Body

Cover the outer appearance of the car handle; this is part where the user will pull up to open the car's door. The original part usually built up by a good material and come with original colour of car.

Bone Structure

Part that cover the sides and top of the handle so that the user cannot see what is at inside, the above part of bone structure usually a thicker compared to the side of the bone structure since the top side resist the spring force that come from the mechanical system of the door handle from inside.

Leaf

Locate at along the bottom surface of main body with a hump shape. The arc of the hump is toward inside to help the user to pull up the handle in the slippery case. In the raining day, the hump shape also prevents the water from entering the inside of the handle that may cause corrosion to the spring and other metal part.

3.2 Design Improvement

With the parts chosen, the improvement of the parts was conducted through several steps. The first step was to compare the existing part design with another car manufacturer's model. In this research, the existing part was compare to 5 other car models. The part was compared by its design structure. Below was the car models that been used as references in this research:

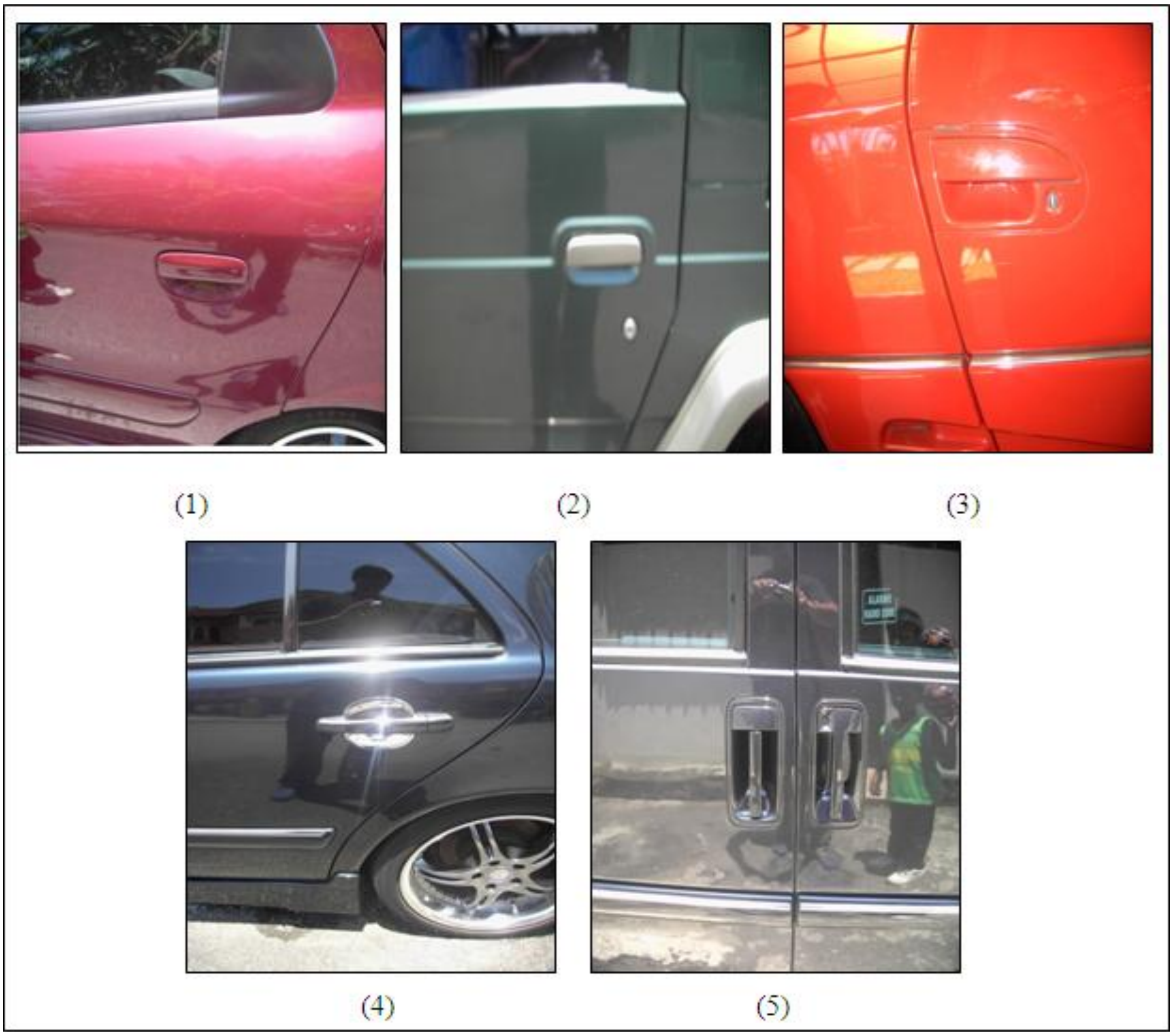


Fig. 5: (1) Citroen Xsara, (2) Jeep Safari Snorkel, (3) Mitsubishi GTO,
(4) Mercedes Benz, (5) Citroen C8 MPV

From these 5 samples, each part was examined and compared its pros and cons in the design engineering. Thus, from here the possible upgrade of the current design for the Perodua's Kancil car handle was develop and then using the FMEA, the lowest value of design's RPN will be consider as the best upgrade or design to replace the current part design.

3.3 Fabrication and Design Process

There are several steps that were followed in this research fabrication process. All flow of the steps known as fabrication methodology. As it name called, it is simply the way or method that cover all the aspect from the starting stage until to the final stage which is to get the product.

3.3.1 Fabrication Methodology

For this research, the tasks were divided into certain steps. These steps or methodology are believed to be this research guidance in conducting the design process of the final products. Below are the methodologies that were followed to complete the designs:

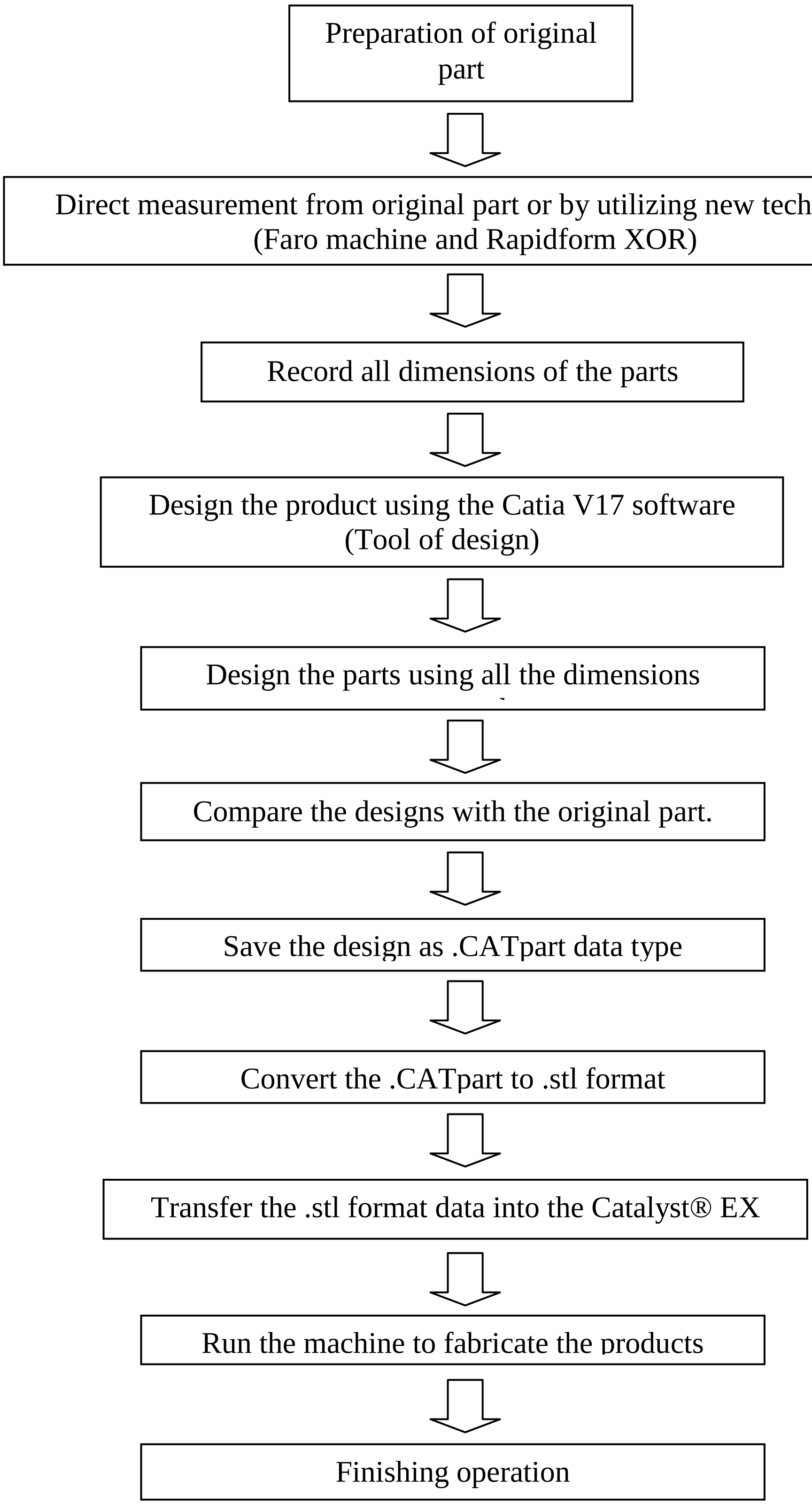


Fig. 6: Methodology of design process

Faro machine and Rapidform XOR were the tools used to get direct measurement from original part or by utilizing new technology. Faro machine is like an arm robot with the probe and laser at the end of the arm. The laser and probe (look like pistol) is use to scan the target object than later the result is shown in the Rapidform XOR software. The scan object is reflected the ray and produce ready for the faro machine. This reading converted in term of surface of product by the thousands of dot. Rapidform XOR is the interface where the product that already scans completely later adjusted to improve the surface.

First setup the part to be scan by Faro machine. Since the surface is shine, spray a powder to the product surface before the Faro machine can detect the surface shape. The part need to be fixing so that the Faro arm easy to scan the whole part. Faro machine was used to scan the outer surface (front side of outer handle).

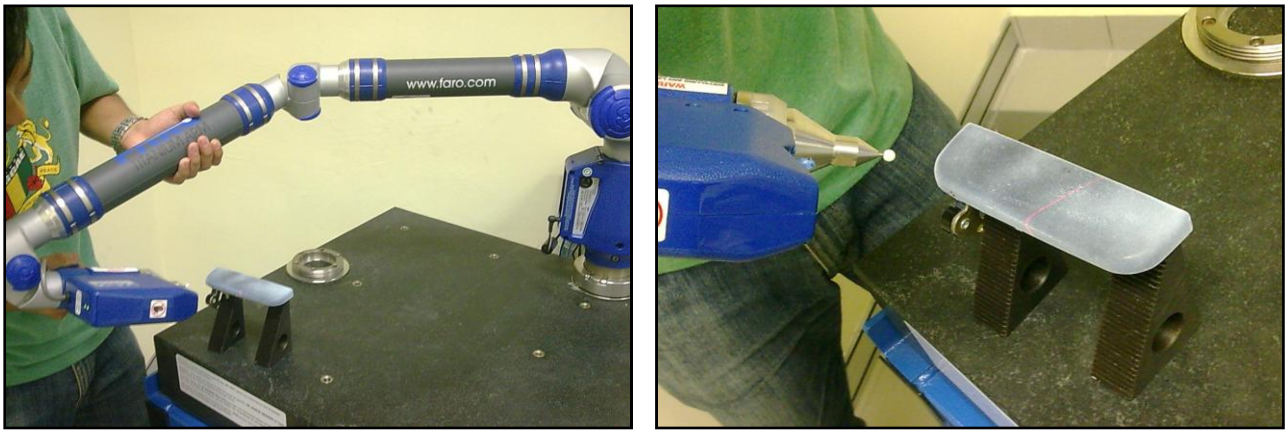


Fig. 7: Application of Faro machine

Faro machine can be move in 360° degree and at 12 degree of freedom. The good scan can be obtain through training and distance from the object. In addition, the scan is limited by the work space of the arm robot.

To fabricate the prototypes, Fused Deposition Machine (FDM) was chosen. The specific model of this machine was the Dimension SST 768 machine. Below were the machine and its build and support material for producing the prototypes:

Part Number	Description
Build Material	
340-20000	White ABS Filament Cartridge
340-20200	Black Filament Cartridge
340-20300	Red Filament Cartridge
340-20400	Blue Filament Cartridge
340-20500	Green Filament Cartridge
340-20600	Yellow Filament Cartridge
340-20800	Steel Gray Filament Cartridge
Support Material	
340-30200	Soluble Support Cartridge
300-00600	Soluble Concentrate

Fig. 8: Dimension SST 768 machine and its build material and support material

Dimension machines used Catalyst® EX software. This software will automatically imports STL files, orients the part, slices the file, generates support structures (if necessary), and creates a precise deposition path to build the model. Multiple models can be packed within the bounding box to maximize efficiency. Catalyst® EX are also provides file management capabilities, build time, material status and system status information. For developing support structure, Catalyst® EX software automatically creates any needed support structures to complete the part.

Next, FMEA were used in order to try to track and traces down all the possibilities that might occur in the new designs. From the results, it will help to produce a product with the best design that gives consumer the maximum quality available.

For this research, Design FMEA (DFMEA) was used where it focuses on potential failure modes of products caused by design deficiencies and to analyze functions and combination of the target part. The analysis done here is continuous assessment where the improvement is result as the improvement of previous product. The cycle is continuous done until the perfect design with very little RPN number is determined. The FMEA was conducted both before and after the upgrade of the current part design.

Referring to Kmenta, S., Ishii, K., 2000, these are the basic steps in conducting FMEA:

1. Describe the product/process and its function.

   Identify those product/process uses that fall within the intended function and which ones fall outside. It is important to consider both intentional and unintentional uses since product failure often ends in litigation, which can be costly and time consuming.

2. Create a Block Diagram of the product or process.

   A block diagram of the product/process should be developed. This diagram shows major components or process steps as blocks connected together by lines that indicate how the components or steps are related.

3. Complete the header on the FMEA Form worksheet.

   Details such as the "Product/System, Subsystem, Component, Design Lead, Prepared By, Date, Revision (letter or number)", and "Revision Date". Modify these headings as needed.

4. Use the diagram prepared above to begin listing items or functions.

   If items are components, list them in a logical manner under their subsystem/assembly based on the block diagram.

5. Identify Failure Modes.

   A failure mode is defined as the manner in which a component, subsystem, system, process, etc. could potentially fail to meet the design intent. Examples of potential failure modes include:

6. A failure mode in one component can serve as the cause of a failure mode in another component.

   Each failure should be listed in technical terms. Failure modes should be listed for functions of each component or process step. At this point the failure mode should be identified whether or not the failure is likely to occur.

7. Describe the effects of those failure modes.

   A failure effect is defined as the result of a failure mode on the function of the product/process as perceived by the customer. It should be described in terms of what the customer might see or experience should the identified failure mode occur.

8. Establish a numerical ranking for the severity of the effect.

   A common industry standard scale uses 1 to represent no effect and 10 to indicate very severe with failure affecting system operation and safety without warning. The intent of the ranking is to help the analyst determine whether a failure would be a minor nuisance or a catastrophic occurrence to the customer.

Rating	Severity Description
1	The effect is not noticed by the customer.
2	Very slightly effect noticed by the customer; does not annoy or inconvenience customer.
3	Slight effect that causes customers annoyance, but they do not seek service.
4	Slight effect, customer may return product for service.
5	Moderate effect, customer requires immediate service.
6	Significant effect causes customer dissatisfactions, may violate a regulation or design code.
7	Major effect, system may not operable, elicits customer complaints, may cause injury.
8	Extreme effect, system is inoperable and a safety problem. May cause severe injury
9	Critical effect, complete system shutdown, safety risk.
10	Hazardous, failure occurs without warning, life threatening.

Table 1: Rating for Severity of Failure.

9. Identify the causes for each failure mode.

   A failure cause is defined as a design weakness that may result in a failure. The potential causes for each failure mode should be identified and documented.

10. Enter the Probability factor.

    A numerical weight should be assigned to each cause that indicates how likely that cause is (probability of the cause occurring).

Rating	Description of Occurrence
1	Extremely remote
2	Remote, very unlikely
3	Very slightly chance of occurrence
4	Slight chance of occurrence
5	Occasional occurrence
6	Moderate occurrence
7	Frequently occurrence
8	High occurrence
9	Very high occurrence
10	Extremely high occurrence

Table 2: Rating for Occurrence of Failure.

11. Identify Current Controls (design or process).

    Current Controls (design or process) are the mechanisms that prevent the cause of the failure mode from occurring or which detect the failure before it reaches the Customer. Each of these controls should be assessed to determine how well it is expected to identify or detect failure modes. After a new product or process has been in use previously undetected or unidentified failure modes may appear. The FMEA should then be updated and plans made to address those failures to eliminate them from the product/process.

12. Determine the likelihood of Detection.

    Detection is an assessment of the likelihood that the Current Controls (design and process) will detect the Cause of the Failure Mode or the Failure Mode itself, thus preventing it from reaching the Customer.

Rating	Description of Detection
1	Almost certain to detect
2	Very high chance of detection
3	High chance of detection
4	Moderately high chance of detection
5	Medium chance of detection
6	Low chance of detection
7	Slight chance of detection
8	Remote chance of detection
9	Very remote chance of detection
10	No chance of detection, no inspection

Table 3: Rating for Detection of Failure.

13. Review Risk Priority Numbers (RPN).

    The Risk Priority Number is a mathematical product of the numerical Severity, Probability, and Detection ratings:

    RPN = (Severity) x (Probability) x (Detection)

    The RPN is used to prioritize items than require additional quality planning or action.

14. Determine Recommended Action(s) to address potential failures that have a high RPN.

    These actions could include specific inspection, testing or quality procedures; selection of different components or materials; de-rating; limiting environmental stresses or operating range; redesign of the item to avoid the failure mode; monitoring mechanisms; performing preventative maintenance; and inclusion of back-up systems or redundancy.

15. Assign Responsibility and a Target Completion Date for these actions.

    This makes responsibility clear-cut and facilitates tracking.

16. Indicate Actions Taken.

    After these actions have been taken, re-assess the severity, probability and detection and review the revised RPN's. Are any further actions required or not.

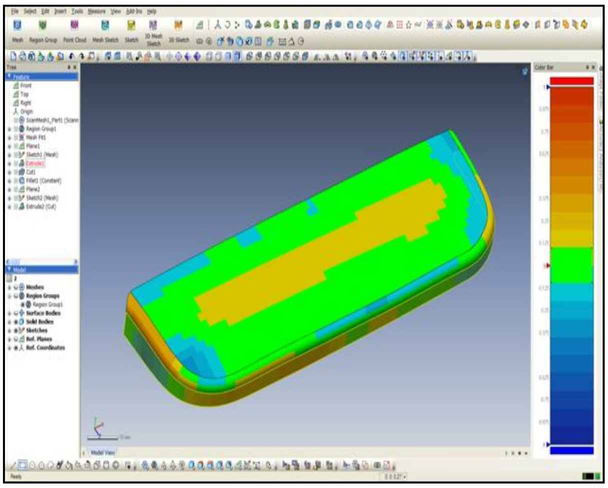
17. Update the FMEA.

As the design or process changes, the assessment changes or new information becomes known.

4.0 RESULTS AND DISCUSSION

4.1 Design Analysis

Using the Faro machine, the dimensions of the original part was noted down since the result of the direct measurement and this technology is similar.



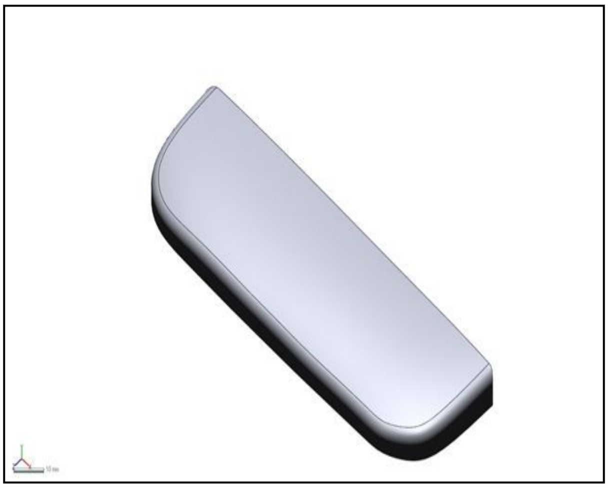
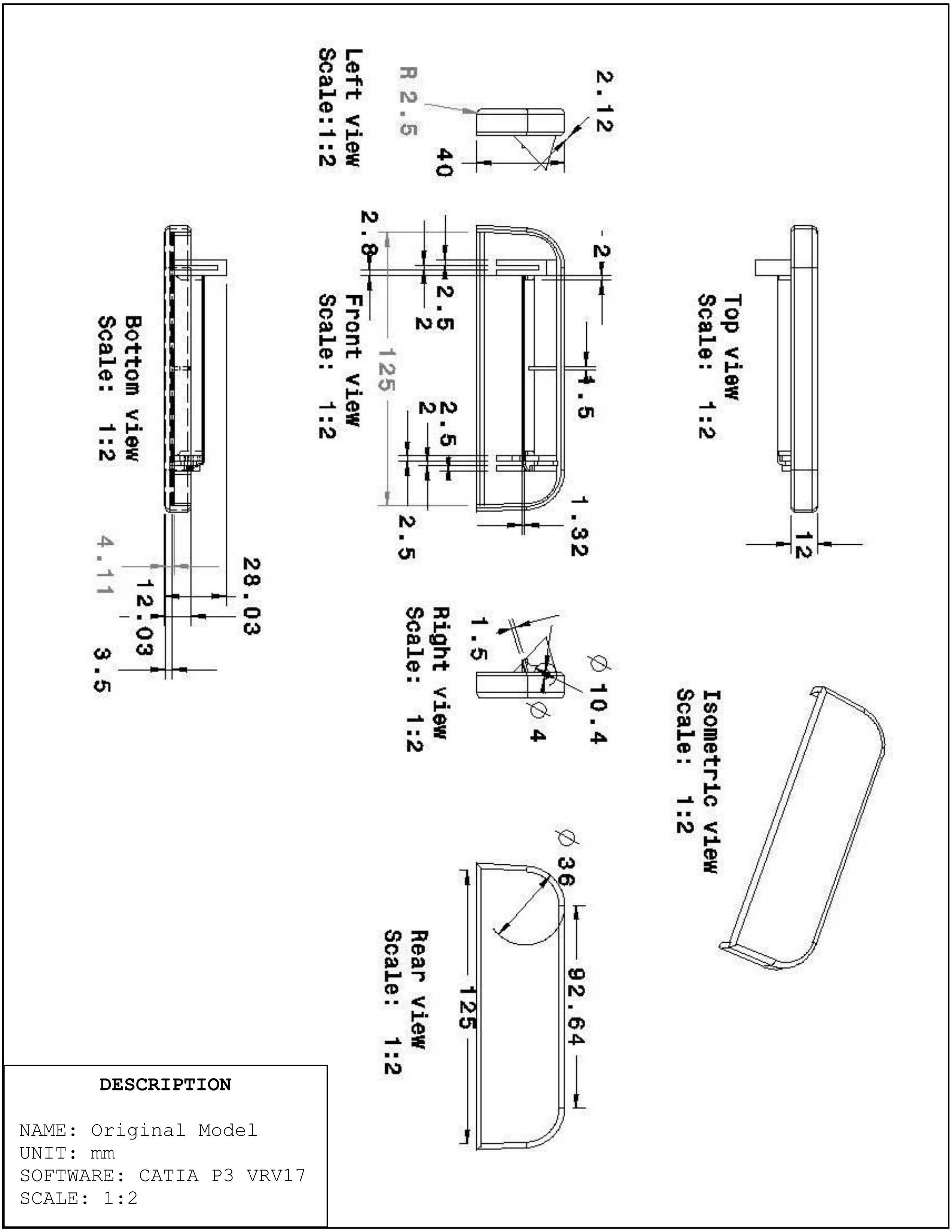


Fig. 9: Part after modification using Rapidform XOR software

The original dimensions of the part were described as stated:

Original Design:



4.2 Design Improvement

In this research, there were 3 most suitable and relevant upgrade of the current part. The table below shows the improvement of each design:

Improvement / Design	Fins	Main Body	Bone Structure	Leaf
1	Thick by 0.5 mm + Chamfer	Reduce by 0.5 mm + skeleton support 1mm	No change	No change
2	Reduce by 0.5 + skeleton support 1mm	Thick by 0.5 mm	Chamfer support	Remove (flat)
3	Add support pile + Another layer	Add skeleton support by 0.4 mm	Support	Remove (flat)

Table 4: Specification improvement of each design

This improvement was agreed to be the best upgrade for the current part design as compared to the other 5 samples of different car's manufacturers. These design that was design using the CATIA P3 Version 17. Below were the CAD drawings and dimensions of each design:

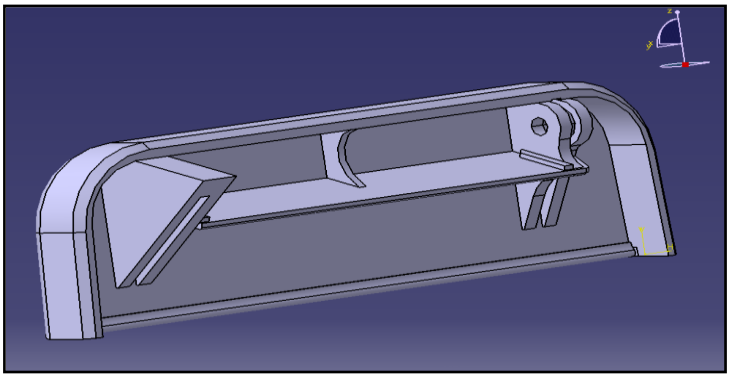


Fig. 10: Original Design

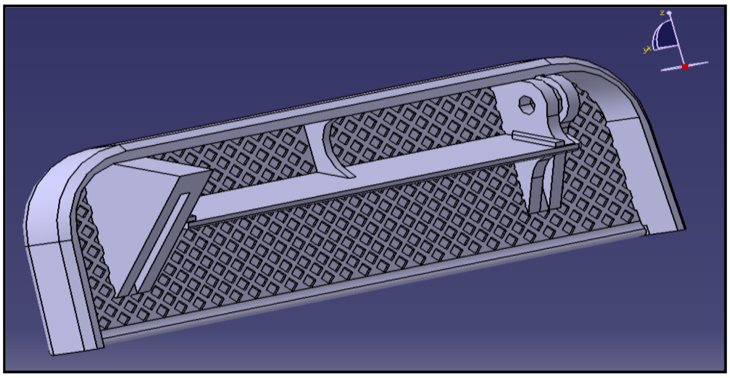


Fig. 11: Design 1

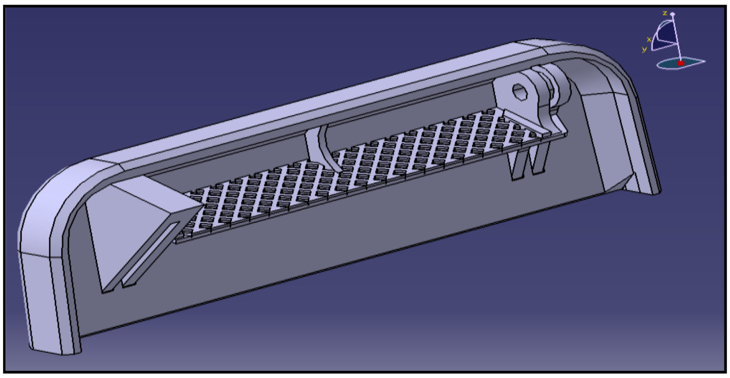


Fig. 12: Design 2

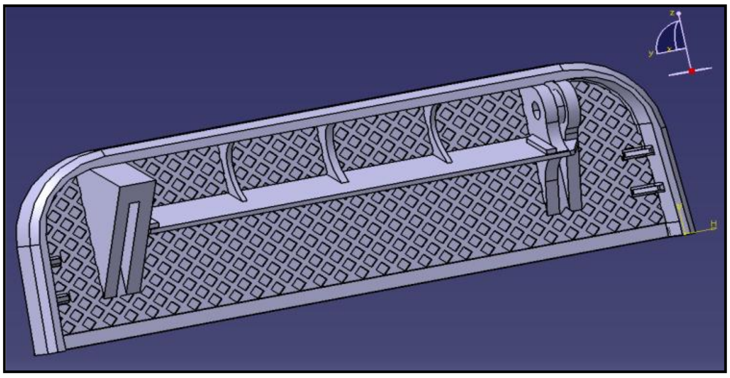
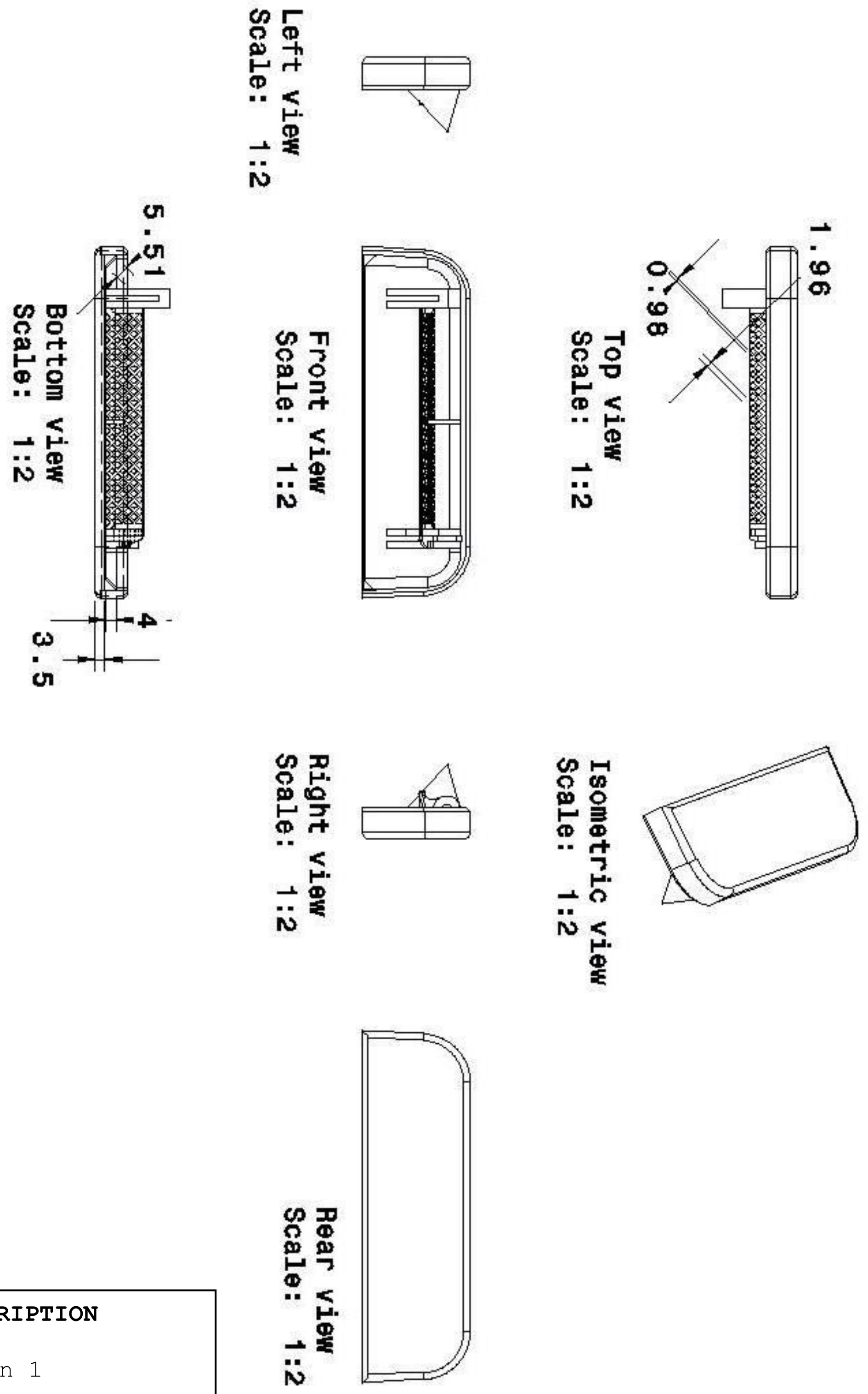


Fig. 13: Design 3

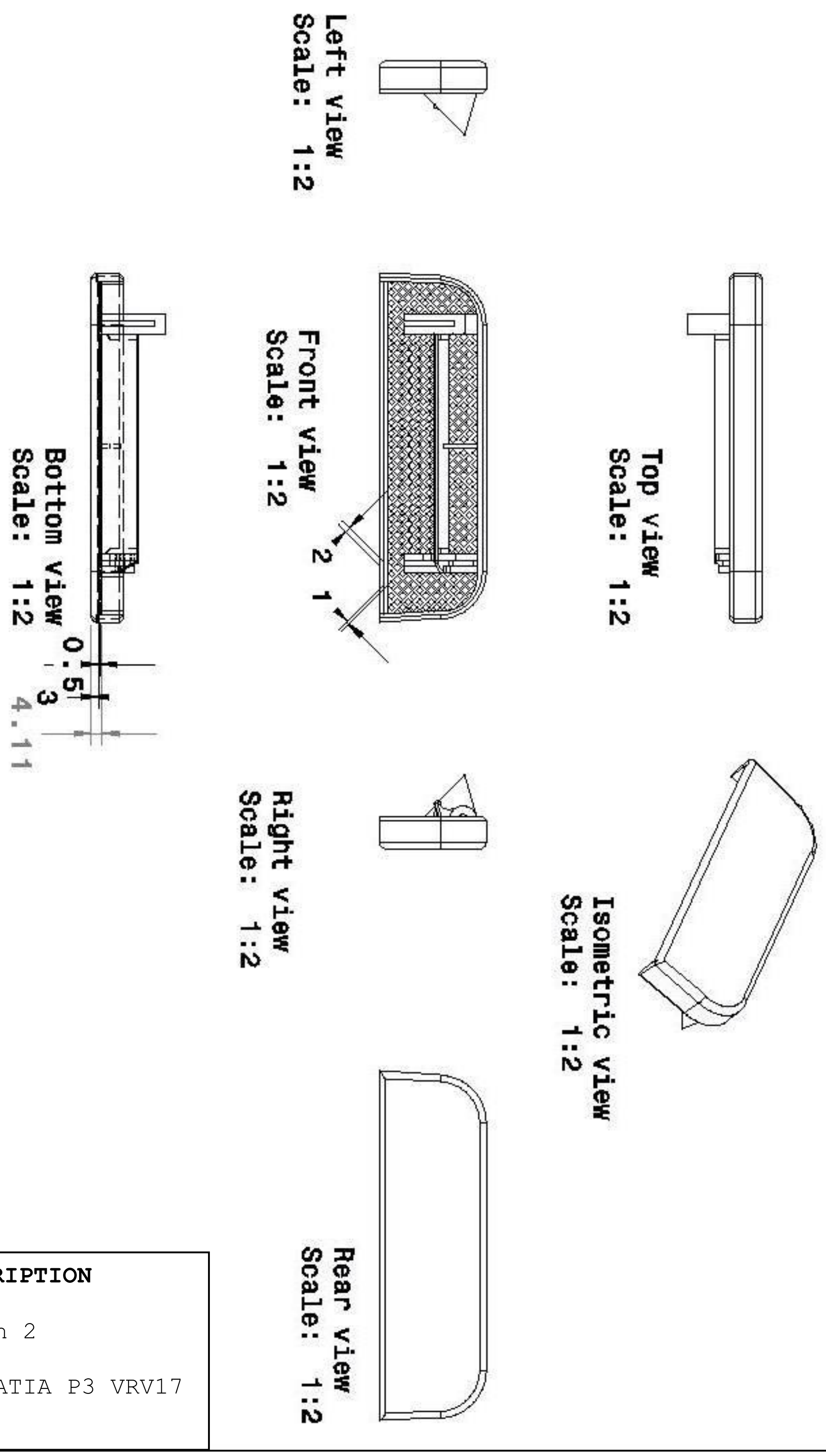
Design 1:



DESCRIPTION

NAME: Design 1
UNIT: mm
SOFTWARE: CATIA P3 VRV17
SCALE: 1:2

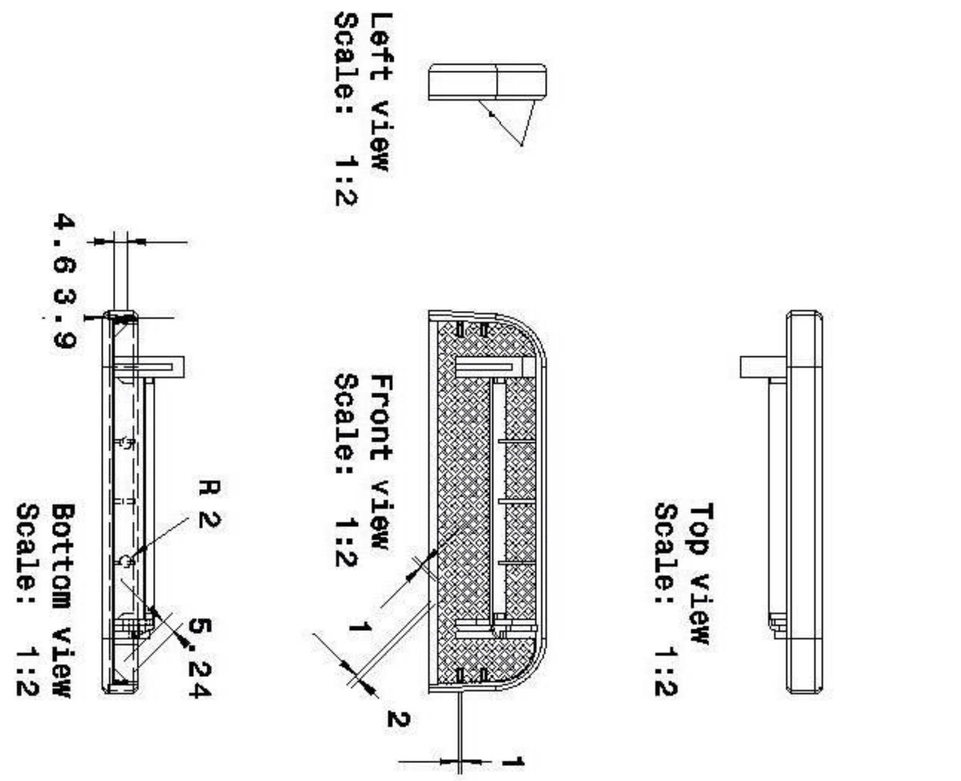
Design 2:

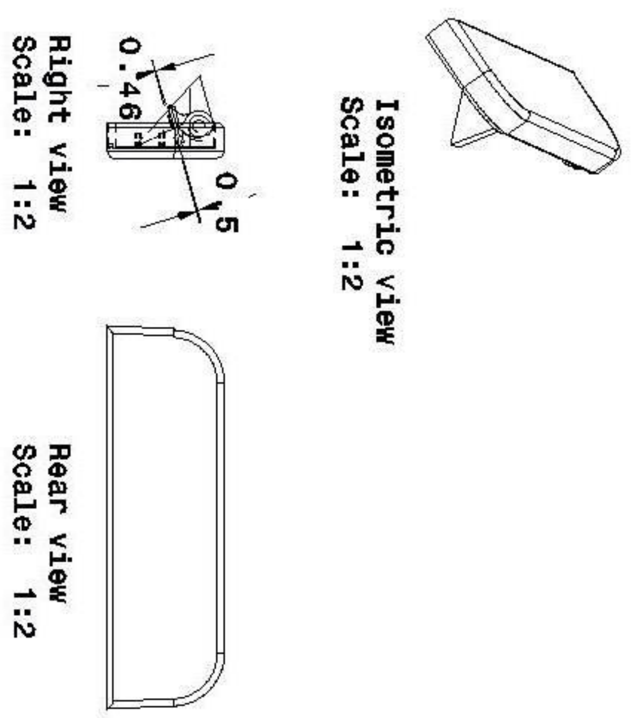


DESCRIPTION

NAME: Design 2
UNIT: mm
SOFTWARE: CATIA P3 VRV17
SCALE: 1:2

Design 3:





DESCRIPTION

NAME: Design 3
UNIT: mm
SOFTWARE: CATIA P3 VRV17
SCALE: 1:2

4.3 Fabrication and Design Process.

After the CAD was design, the next process was to fabricate the designs. For the build material, acrylonitrile butadiene styrene (ABS) plastic in standard white was used; the standard code is 340-20000-White ABS Filament Cartridge. The support material used here is 340-30200- Soluble Support Cartridge.

The fabrication processes were as followed:

4.3.1 Computer Aided Design File Preparation

Before fabricating a part into machine, the STL file has to be inserted into the machine interfaced software. After that the process may begin. The aforementioned Catalyst® EX is used for this purpose. The STL file is read into Catalyst® EX, and is displayed graphically on screen in the Cartesian coordinate system (-x,-y, and -z). Also shown is the bounding box, a dashed three dimensional box represent the maximum build envelope of the FDM chamber. Catalyst® EX gives some option for fabrication method used such as the layer resolution, model interior, support fill, number of copies, STL units, and STL scale. Catalyst® EX software have user-friendly interface, all the input needed is placed by sequence and by page. So it is easy for us to us this software to further the project completion.

For higher definition models, thinner slices may be used but this will increase the time required to complete a part build. As for less accuracy parts can be built much faster using thicker slice value. Once the slice completed for the whole part(s), the file can be save for future action and alternation.

4.3.2 Part Size

Before fabricating the product, design’s part size must be set. The part must be confirmed to fit exactly in the bounding box. If the part is not within the box, a scaling option might necessary. Since the part is within the bounding box, so there are no necessary for the scaling option. The part must also re-arrange correctly since the fabricating process of the multiple designs in a one single run.

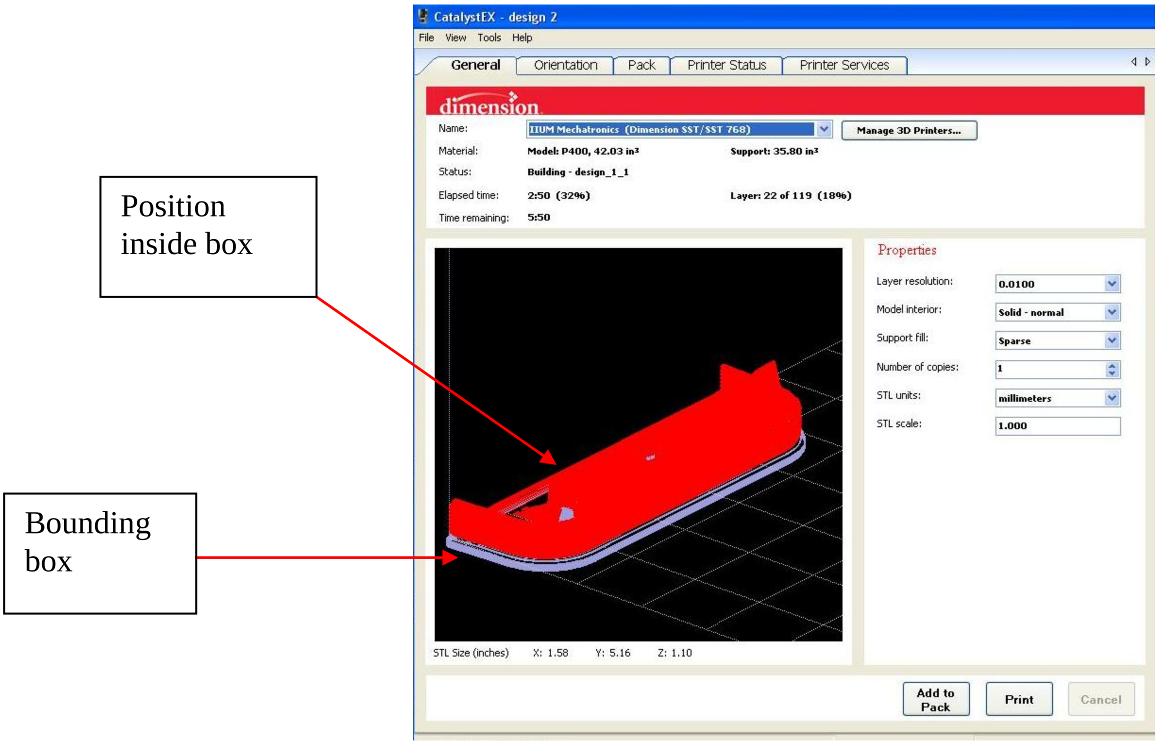


Fig. 14: Catalyst® EX software interface

4.3.3 Orientation / positioning

In this research, the position of the parts was as lying by the most surface at the bottom side, so the use of support material will be reduce. With this, it can save the time of fabrications and also save the materials that will be used for the prototypes.

4.3.4 Slicing

The next step was the slicing. It is a software operation that creates thin, horizontal cross sections of the STL file that gives the instruction to the machine to do the fabrication operations. When finish with the slicing, click PRINT option to start the fabrication process.

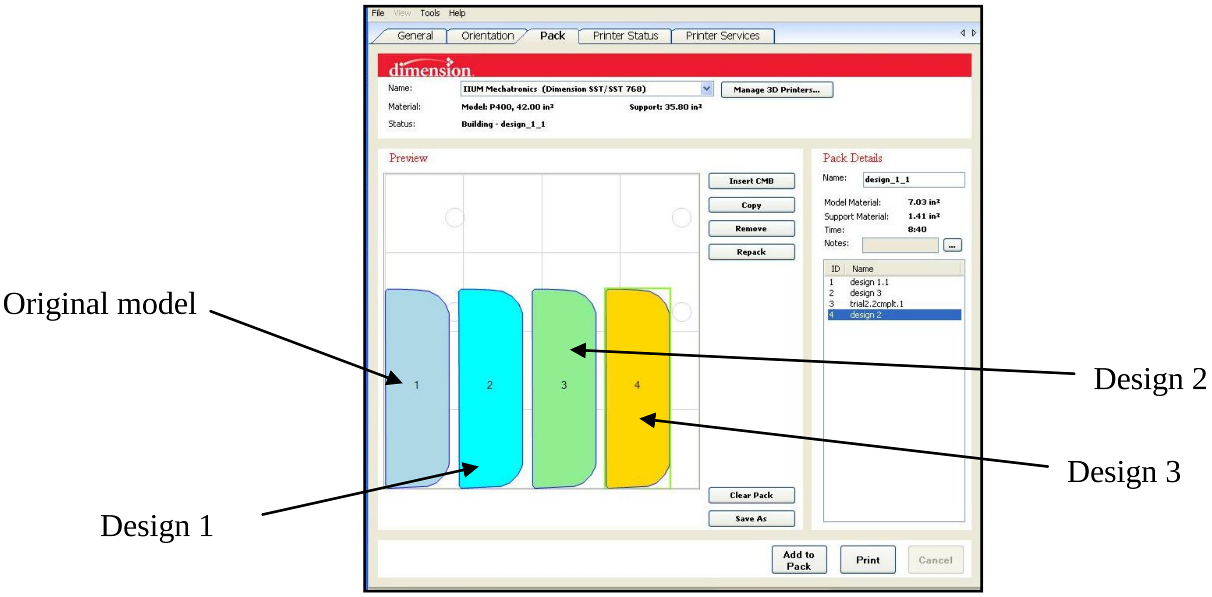


Fig. 15: Complete orientation from top view

4.3.5 Build Parameters

Catalyst® EX software has optimum build parameters set as default for slice thickness and material chosen, built it will also allow manual intervention so that can vary several different settings. Some parameters can be tweaked to decrease build time, model weight, and the amount of material required for fabrication.

4.3.6 Building a Part

The software setup requires most of the time for preparation, once the machine begin to fabricate, the will just waiting time for completion only. Thus, the prototypes were created in a single run.

Fig. 16: Fabrication completed

4.3.7 Finishing a Fused Deposition Modeling Part

Using these machine, finishing operation are slightly not needed or if it is required, it just an easy operation. For the prototypes, soluble support technology was used to remove the support material to be peeled away easily by hand with knifes or pliers. The soluble liquid concentration was used with certain temperature and dawn the part into it to remove any of other unnecessary materials in our part. For this research, it takes almost 12 hours to take out completely all the support structure.

Fig. 17: Finishing part by sink the parts into container (about 70°C)

Fig. 18: The finished product.

To improve the shape, the materials are easy to polish by sanding, and the ABS plastic parts may be made very smooth by wiping them down with a cloth moistened in acetone or a similar light solvent. For this finishing, the sanding process was eliminated since to maintain the dimensions accuracy.

In this research, all the necessary parameters that were used in this fabrication are:

Properties:

Layer resolution: 0.010 in or 0.245mm

Model interior: Solid – normal

Support fill: Sparse

Number of copies: 1

STL units: millimeters

STL scale: 1.000

STL size: X=40.132mm Y=131.064mm Z=27.94mm

Estimated build time: 8hrs 40mins

Model material used: 7.027 in^3 ~ 115.152 cm^3

Support material used: 1.413 in^3 ~ 23.155 cm

In the fabrication stage, the prototypes got unsmooth curve at the edge surface that use chamfer tool and got staircase effect at the slope surface. By using the minimum layer resolution, the staircase will be reducing but resulting in the longer production. For this research, the default setting was used which the product is acceptable.

4.4 FMEA Applications

By referring the given FMEA Worksheet, all of the possible defects from the new design managed to be traced. From here, the best design of the parts can be choose as the most practical car's door handle for the Perodua's Kancil.

Here is the FMEA Worksheet, where all the number and action to be taken to fill up the table had been agreed by members of group. Several improvements have been done in order to make the result sense to the realities of the product.

The analysis done here is continuous assessment where the improvement is result as the improvement of previous product. The cycle is continuous done until the perfect design with very little RPN number is determined.

FMEA Worksheet														
Product Name: **Design 1** for Left back outer door handle for Perodua Kancil design.														
Part Design	**Failure Mode**	**Effect**	**Sev**	**Causes**	**Occ**	**Current Control**	**Det**	**RPN**	**Actions Taken**	**Sev**	**Occ**	**Det**	**RPN**
Fins	Broken	Injury	6	Not suitable of material used.	5	None	1	30	Use ABS material	5	4	1	20
	Crack	Can't open the door.	6	Wear and tear effect.	5	Replace the part.	5	150	Make the part a little more thick and chamfer the part to remove sharp edge	5	4	4	80
Bone Structure	Broken.	Injury	5	Not suitable of material used.	5	None	1	25	Use ABS material	4	4	1	16
	Crack	Functional non-effective	5	Wear and tear effect.	5	Double layer paint applied.	3	75	No change to part	4	4	3	48
				Bad handling by the user.	5	Double layer paint applied.	3	75	No change to part	4	4	3	48
Main Body	Broken.	Injury	6	Not suitable of material used.	6	None	1	36	Use ABS material	5	4	1	20
	Crack	Hazardous due to paint's side effects on user.	6	Wear and tear effect.	6	Double layer paint applied	2	72	Add skeleton layer to give more strength	5	5	2	50
				Bad handling by the user.	6	Plaster the cracked part.	2	72	Reduce thickness of part	5	5	2	50
Leaf	Broken.	Injury	5	Not suitable design and material used.	6	Replace the part.	4	120	Use ABS material	5	6	4	20
	Crack.	Hazardous due to paint's side effects on user.	5	Wear and tear effect.	6	Replace the part.	4	120	No change to part	5	6	4	120
	Stretch.			Bad handling by the user.	6	Repaint the part when the paint started to fell.	4	120	No change to part	5	6	4	120

FMEA Worksheet

Product Name: **Design 2** for Left back outer door handle for Perodua Kancil design.

Part Design	Failure Mode	Effect	Sev	Causes	Occ	Current Control	Det	RPN	Actions Taken	Sev	Occ	Det	RPN
Fins	Broken	Injury	6	Not suitable of material used.	5	None	1	30	Use ABS material	5	4	1	20
	Crack	Can't open the door.	6	Wear and tear effect.	5	Replace the part.	5	150	Add skeleton support	4	4	3	48
Bone Structure	Broken.	Injury	5	Not suitable of material used.	5	None	3	75	Use ABS material to give more strength	4	4	1	16
	Crack	Functional non-effective	5	Wear and tear effect.	5	Double layer paint applied.	3	75	Chamfer support to give more strength	3	3	3	27
				Bad handling by the user.	5	Double layer paint applied.	3	75	Chamfer support to give more strength	3	3	3	27
Main Body	Broken.	Injury	6	Not suitable of material used.	6	None	1	36	Use ABS material	5	4	1	20
	Crack	Hazardous due to paint's side effects on user.	6	Wear and tear effect.	6	Double layer paint applied	2	72	Make the main body a little more thick	4	4	2	32
				Bad handling by the user.	6	Plaster the cracked part.	2	72	Make the main body a little more thick	4	4	2	32
Leaf	Broken.	Injury	5	Not suitable design and material used.	6	Replace the part.	4	120	Use ABS material	5	6	4	120
	Crack.	Hazardous due to paint's side effects on user.	5	Wear and tear effect.	6	Replace the part.	4	120	Cancel out the part by making it flat	3	2	2	12
	Stretch.			Bad handling by the user.	6	Repaint the part when the paint started to fell.	4	120	Cancel out the part by making it flat	3	2	2	12

FMEA Worksheet													
Product Name: **Design 3** for Left back outer door handle for Perodua Kancil design.													
Part Design	**Failure Mode**	**Effect**	**Sev**	**Causes**	**Occ**	**Current Control**	**Det**	**RPN**	**Actions Taken**	**Sev**	**Occ**	**Det**	**RPN**
Fins	Broken	Injury	6	Not suitable of material used.	5	None	1	30	Use ABS material	5	4	1	20
	Crack	Can't open the door.	6	Wear and tear effect.	5	Replace the part.	5	150	Add another layer	3	2	3	18
Bone Structure	Broken.	Injury	5	Not suitable of material used.	5	None	3	75	Use ABS material	4	4	1	16
	Crack	Functional non-effective	5	Wear and tear effect.	5	Double layer paint applied.	3	75	Add support to give more strength	3	3	3	27
				Bad handling by the user.	5	Double layer paint applied.	3	75	Add support to give more strength	3	3	3	27
Main Body	Broken.	Injury	6	Not suitable of material used.	6	None	1	36	Use ABS material	5	4	1	20
	Crack	Hazardous due to paint's side effects on user.	6	Wear and tear effect.	6	Double layer paint applied	2	72	Add skeleton support	3	3	2	18
				Bad handling by the user.	6	Plaster the cracked part.	2	72	Add skeleton support	3	3	2	18
Leaf	Broken.	Injury	5	Not suitable design and material used.	6	Replace the part.	4	120	Use ABS material	5	6	4	120
	Crack.	Hazardous due to paint's side effects on user.	5	Wear and tear effect.	6	Replace the part.	4	120	Cancel out the part by making it flat	3	2	2	12
	Stretch.			Bad handling by the user.	6	Repaint the part when the paint started to fell.	4	120	Cancel out the part by making it flat	3	2	2	12

Calculation

Review Risk Priority Numbers (RPN) = (Severity) x (Probability) x (Detection)

Part	Failure	RPN			
		Before	After		
			*Design **1***	*Design **2***	*Design **3***
Fins	Broken	30	20	20	20
	Crack	150	80	48	18
Bone Structure	Broken	75	16	16	16
	Crack (wear)	75	48	27	27
	Crack (bad handling)	75	48	27	27
Main body	Broken	36	20	20	20
	Crack (wear)	72	50	32	18
	Crack (bad handling)	72	50	32	18
Leaf	Broken	120	120	120	120
	Crack	120	120	12	12
	Stretch	120	120	12	12

Table 5: RPN for FMEA analysis for each design

From the calculation, it was to find each part's RPN. Thus, after the calculation, it describes and explains the results in a simple and more effective way by preparing the Pareto chart.

Below were the charts that have been prepared. From the charts, the results was compared and then the best result of the designs will be the most suitable and effective design to be replacing the left back outer door handle for Perodua Kancil design:

Pareto charts:

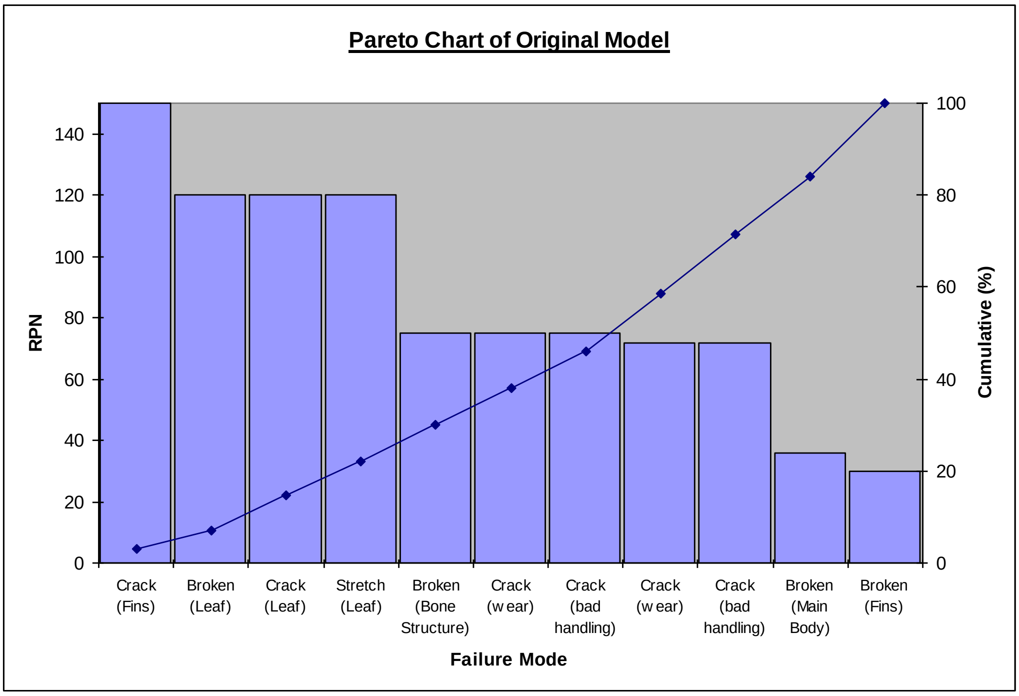


Fig. 19: Pareto Chart of Original Model

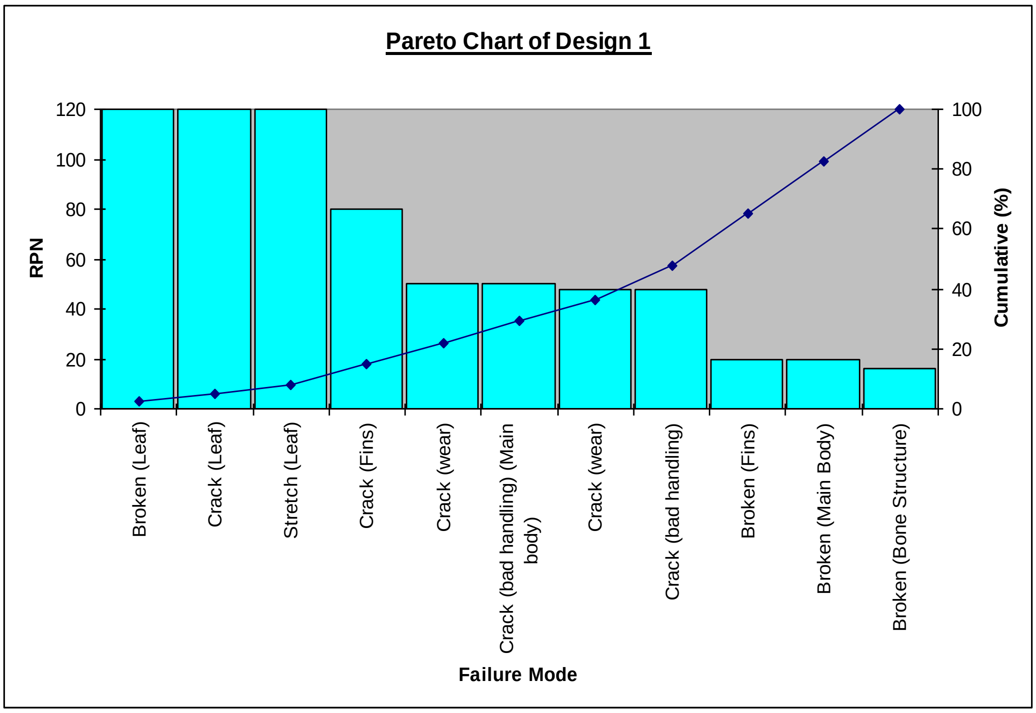


Fig. 20: Pareto Chart of Design 1

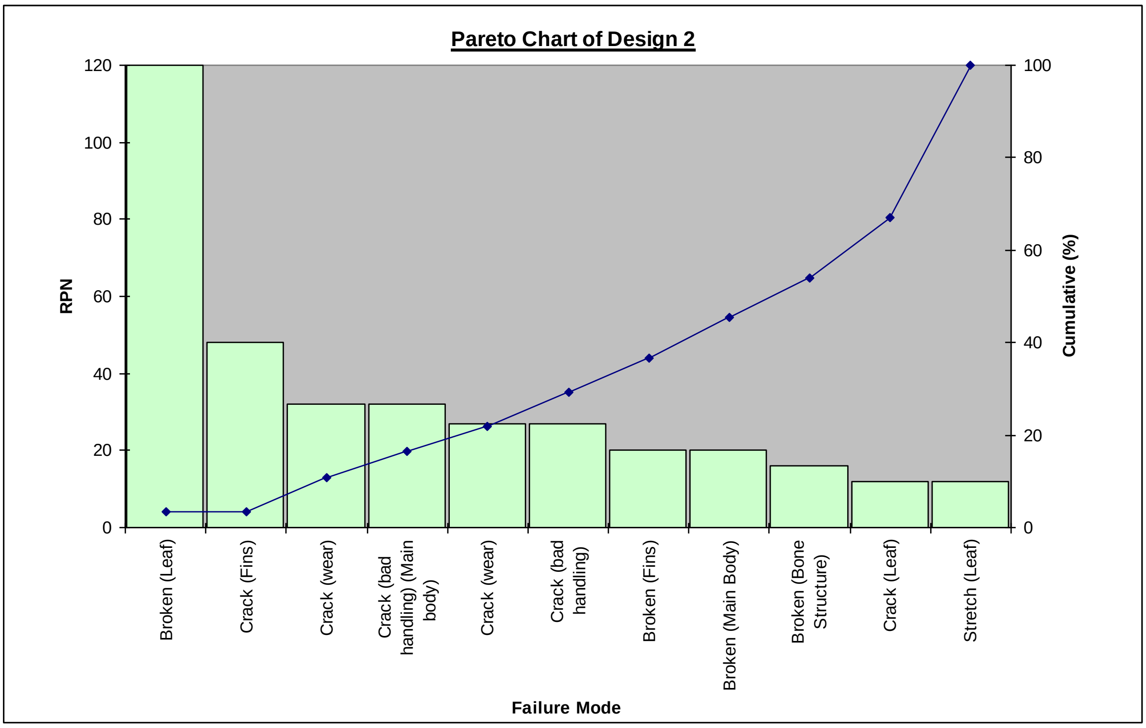


Fig. 21: Pareto Chart of Design 2

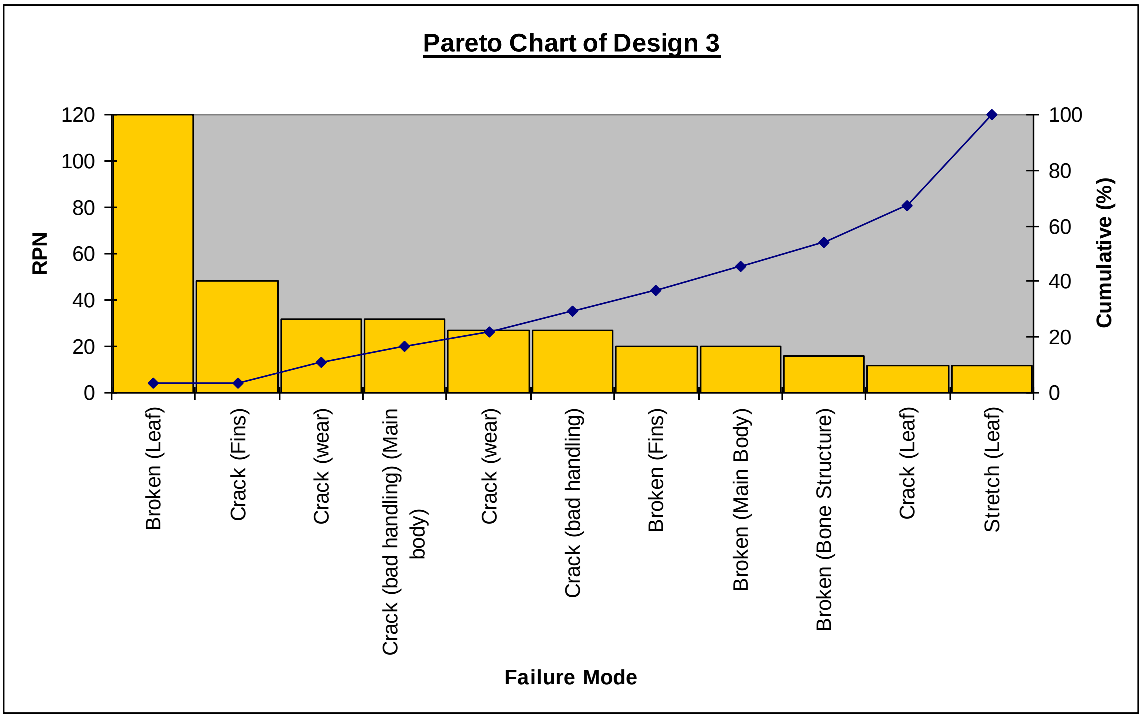


Fig. 22: Pareto Chart of Design 3

Through the FMEA worksheet for all the designs that the best design for the new product will be **DESIGN 3**. Below formula was used to calculate the value by using this formula:

$$\text{Sum of RPN} = \frac{(\text{Total of Before RPN} - \text{Total of Design's RPN})}{\text{Total of Before RPN}} \times 100\%$$

Thus, the results gave the values for each design:

Design 1: 26.8%

Design 2: 61.3%

Design 3: 67.4%

By referring to the pareto chart and calculation above, it is clear that the lowest value of each part will be within our Design 3. Thus, it believed through the FMEA the best design for this research will be **Design 3**.

5.0 CONCLUSION

Within this research, **The Application of Rapid Prototyping Technology and FMEA quality tool in the Development of Automotive component** was applied successfully. It proved that using RP in producing prototypes is much convenient comparing to the traditional method. It saves cost, time, and material usage. The objectives of this research were successfully achieved.

With the designs finished undergo the FMEA; the part designs have been analyzed and all the possibilities of failures that might occur have been tracked down. With that, FMEA can provide an analytical approach, when dealing with potential failure modes and their associated causes. When considering possible failures in a designing a part, factors such like safety, cost, performance, quality and reliability can be detected. FMEA provides an easy tool to determine which risk has the greatest concern, and therefore an action is needed to prevent a problem before it arises. The development of these specifications will ensure the product will meet the defined requirements.

Several technologies can be used to redesign the product. By applying such as Faro machine, the time of design may be reducing depending of the difficulties of the product shape. Direct measurement is also one of method to get the dimension of object. By selecting the proper tool and right method of measurement, the data or measurement gain is very accurate. Through the project, both method of measurement are been used. To increase the accuracy of the measurement, several tool of measurement can because here, not just stick to only one method. The accuracy is 100% if the both result of the measurement give the same reading. Familiarizing with software tool such as Rapidform XOR is useful; to master the software, effort and patience is needed. The software has variety function that can be learn. To built the solid body of the part being scan by faro machine, the solid extrude option has been use here. Designing software such as CATIA V17 is very helpful to generate the design in 2D and 3Dimension. Many functions are available to help the designing phase. Through the project, several options has been used to build up or design the part such as part design option, chamfer tool, sketch tool, transform tool and many more.

There is some improvement for conducting this research in the future. Things as stated below should be consider for the next research:

1. Cost consideration.

   As this research is only for academic purposes, it will be more effective if the cost for producing the prototypes as a functional part to be considered. The machine's application, the materials used, time consumed, and design process flow costs should put into consideration into the research.
2. Different materials used.

   Due to time constraint and material's availability in the university's lab, only acrylonitrile butadiene styrene (ABS) plastic in standard white, standard code is 340-20000-White ABS Filament Cartridge was used as the build material and the support material used was 340-30200- Soluble Support Cartridge. Other type of material should also be use in the research to compare which material is the most suitable material for producing the prototypes.

6.0 REFERENCES

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