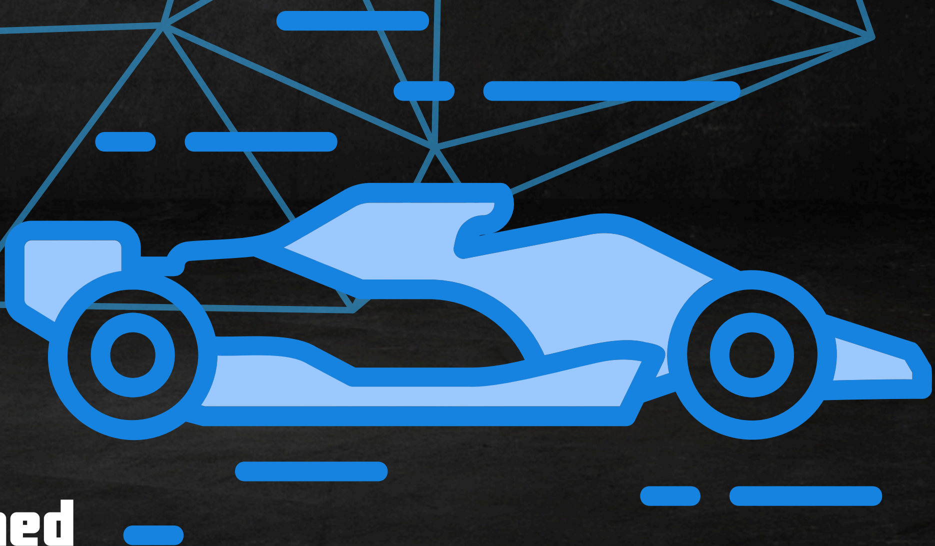
UTM
UNIVERSITI TEKNOLOGI MALAYSIA

F1 In Schools Model Car



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1.0 Introduction

1.1 Product Background:

"F1 in Schools" is an engineering initiative developed to introduce STEM to students across the globe. The program revolves around creating and prototyping a model F1 car, coupled with basic mechanisms, aesthetic design and racing capability. The teams involved then compete to ascertain the best possible model car design. The program is endorsed by F1 and various engineers which contribute by providing reasonable guidelines to students which prioritize safety and practical learning [1].

1.2 Problem Statement:

Despite being an excellent initiative to familiarize students with STEM, the model cars created through "F1 in Schools" often use traditional manufacturing methods such as CNC machining or laser cutting that are wasteful and inefficient. Hence, innovative CAD and manufacturing solutions such as additive manufacturing can be integrated to reinforce the idea of sustainable manufacturing.

1.3 Scope

This study focuses entirely on improving the manufacturing aspect of the model car creation. The reinforcement of the manufacturing aspects are to be done through DfAM (Design for Additive Manufacturing) in its initial stages, and through AM (Additive Manufacturing) at its final stages; Enabling the reinforcement of the initial design and the manufacturing processes used for creation.

2.0 Manufacturing Process

2.1 Introduction

Additive manufacturing (AM) has revolutionized how intricate designs are fabricated, particularly in applications such as F1 racing cars, where precision, lightweight components, and aerodynamic shapes are critical. Hence, Additive Manufacturing and other complementary secondary processes are leveraged to achieve the desired quality and performance of the racing car. This section outlines the steps and considerations into selecting a suitable additive manufacturing for the F1 Schools car, focusing on precision, material choice, and efficiency.

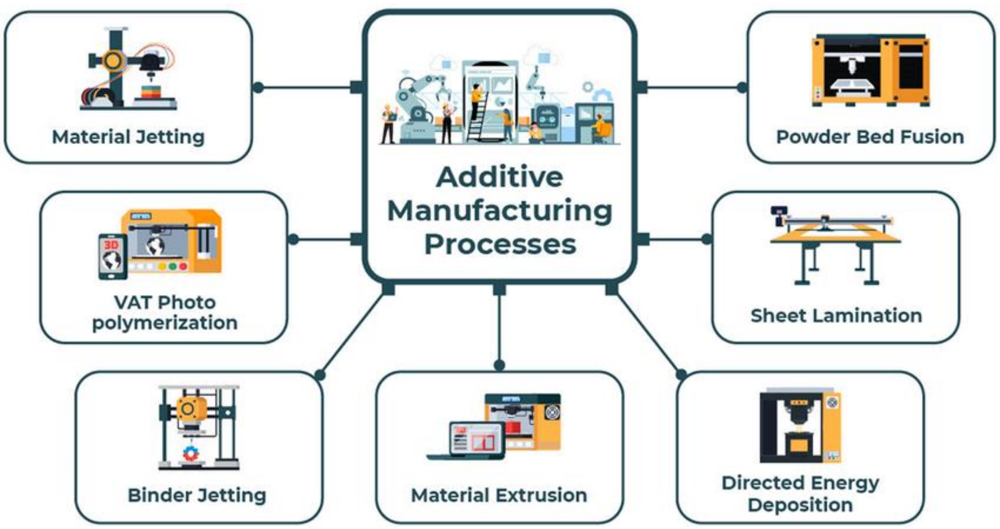

Figure 1: Additive Manufacturing Process

2.2 *Steps involved in Manufacturing Process:*

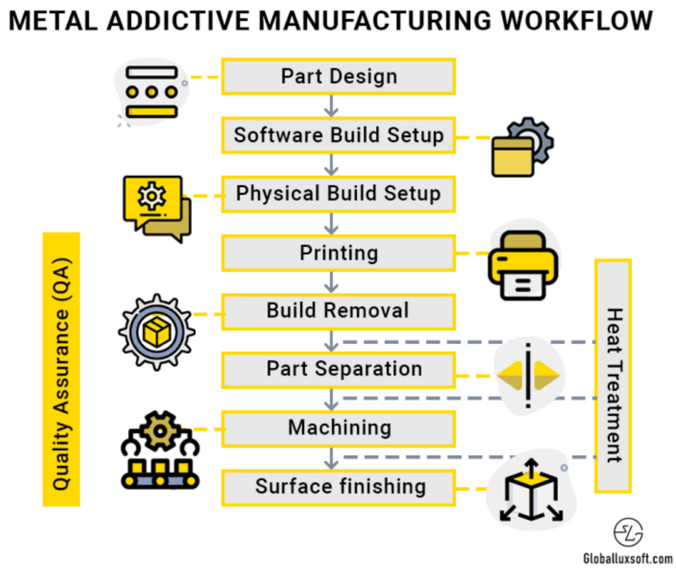

Figure 2: Additive Manufacturing Workflow

The manufacturing process begins with preparing a detailed 3D CAD model of the F1 racing car. The design includes all components, from the streamlined body to intricate parts such as spoilers and wheel mounts. During this phase, aerodynamic principles are carefully applied to optimize the car's performance. Refining curves and edges ensure minimal air resistance, which is critical for achieving high speeds. Additionally, dimensions and tolerances are verified to ensure compatibility during assembly.

2.3 Material Selection

Once the CAD model is prepared, the next step in selecting a suitable additive manufacturing process is by identifying a material that meets all requirements. As the F1 Schools car is utilized in learning and also used for racing, the material utilized must be durable, non-corrosive, extremely light-weight, have good surface finish and require minimal-post processing to reduce cost. As such, the best suited category of materials would be polymers. Hence, PETG resin material is chosen for its lightweight properties and detailed accuracy, ensuring minimal post-processing.

2.4 AM Process Selection

Picking from the AM processes illustrated in figure 1, the best AM process is Vat Photopolymerization. Hence, the commercial technology Stereolithography (SLA) is selected for its precision and ability to produce components with exceptional surface finishes. SLA is utilized to fabricate:

- The aerodynamic body shell for its smooth surface and intricate details.
- Accessories and smaller components such as spoilers and winglets. The SLA resin material is chosen for its lightweight properties and detailed accuracy, ensuring minimal post-processing.

While additive manufacturing handles intricate designs, certain components of the F1School car cannot be manufactured easily through AM. In this instance, traditional machining is employed for structural components which might require greater strength and precision. In particular, the 304 aluminum rods are machined to form the:

- Chassis frame.
- Suspension parts. These components provide the necessary structural integrity and lightweight performance.

Material Selection for Structural Components, the alloy Aluminium 304 was chosen for its high strength-to-weight ratio and excellent corrosion resistance, making it ideal for the demanding conditions of an F1 car. Its machinability ensures precise fabrication of the chassis and other critical parts. The use of ball bearings (606Z) ensures smooth wheel rotation, reducing friction and enhancing overall performance. Epoxy steel and epoxy hardeners are employed to create robust bonds between components, ensuring durability during high-speed operation.

The assembly phase integrates all manufactured parts using appropriate tools and techniques. Key elements include:

- **Ball Bearings 606Z:** Installed in the wheels to ensure smooth rotation and reduce friction.
- **Epoxy Steel & Epoxy Harden:** Applied to bond critical joints, enhancing overall rigidity and durability.

Careful alignment and securing of parts are crucial to ensure seamless performance and functionality.

Post-processing enhances the visual appeal and performance of the F1 car by smoothing the surfaces of SLA-printed parts to achieve a professional finish. This step is crucial for ensuring the components have a sleek and polished appearance. Protective coatings are then applied to prevent wear and environmental damage, extending the lifespan and durability of the parts. Finally, a thorough inspection and testing process is conducted to ensure that all components function as expected, meeting the required performance standards and ensuring the car's overall reliability.

2.2 Reason behind SLA and PETG selection

Elaborating further, SLA was selected due to its ability to create highly precise and intricate designs, which is crucial for achieving the aerodynamic and aesthetic requirements of an F1 car [2]. Its smooth surface finish reduces the need for extensive post-processing, saving time and effort while enhancing the car's professional appearance. The choice of PETG material complements the SLA process for components requiring greater impact resistance and flexibility, as PETG offers excellent strength and minimal warping during printing [3]. These attributes make it a reliable choice for automotive applications where durability and accuracy are paramount. The combination of SLA and PETG allows for an optimal balance between performance and efficiency in manufacturing [4].

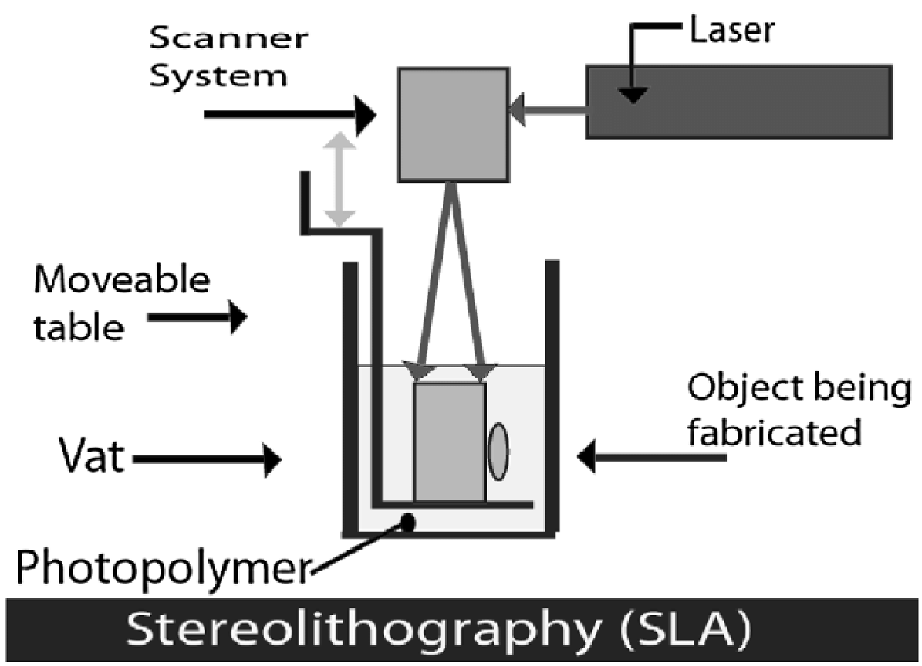

Figure 3 SLA Setup

PETG (Polyethylene Terephthalate Glycol) was chosen for specific components due to its unique properties, which include:

- **Durability:** PETG is highly durable, making it suitable for components subjected to mechanical stress.

- **Impact Resistance:** It offers excellent resistance to impacts, ensuring the car parts can withstand operational stresses.
- **Flexibility:** PETG provides a good balance between rigidity and flexibility, making it ideal for parts requiring slight deformation without breaking.
- **Smooth Printing Process:** It has minimal warping during 3D printing, ensuring precise and reliable fabrication.
- **Chemical Resistance:** PETG resists various chemicals, increasing the longevity of printed components.

These properties make PETG a reliable choice for automotive applications where durability, precision, and cost-effectiveness are essential [5,6].

3.0 Detailed Drawings

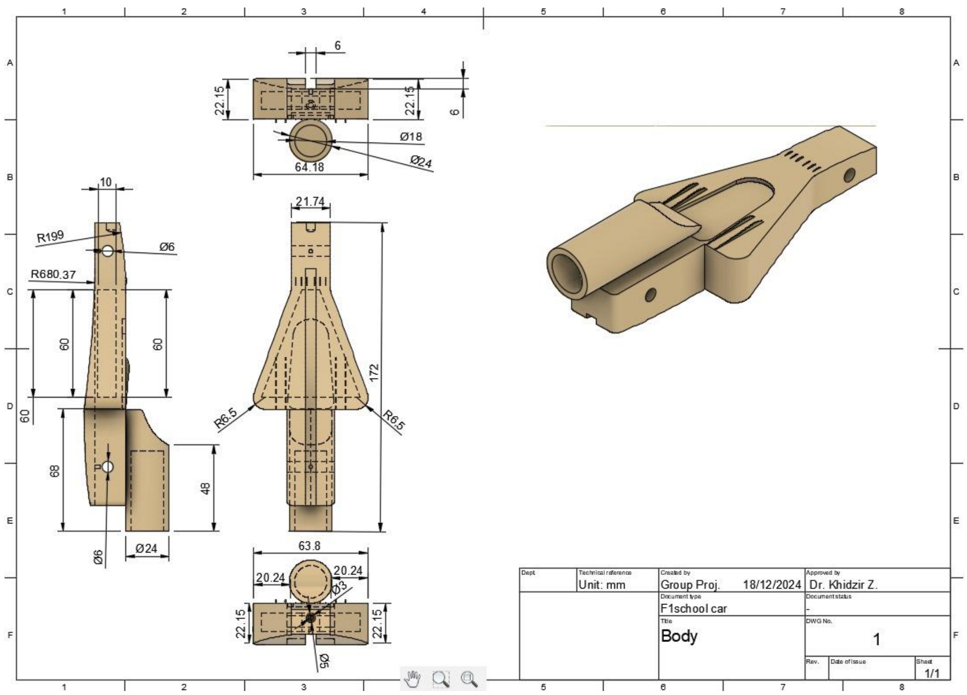

Figure 4 Isometric Car Body Drawing

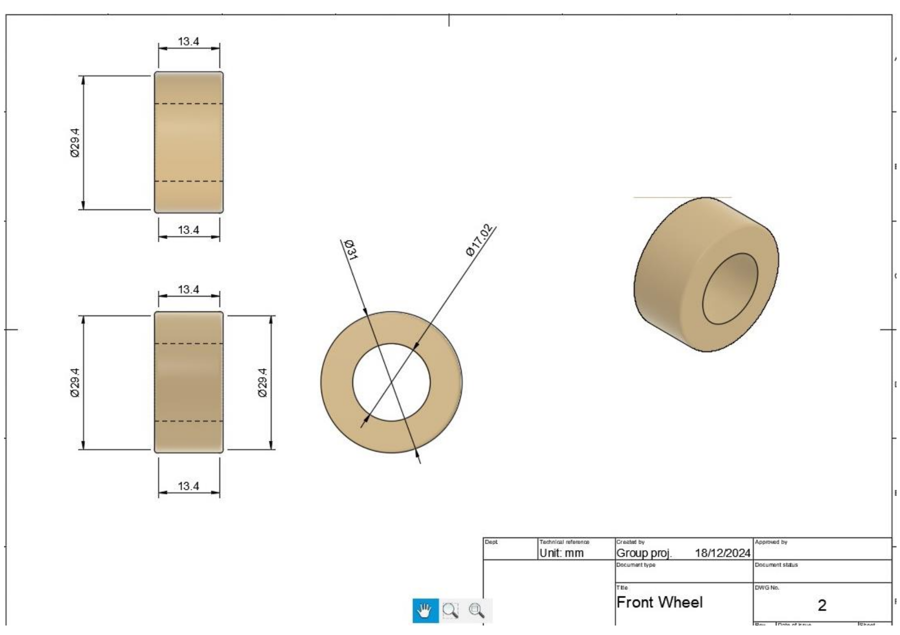

Figure 5 Front Wheel Drawing

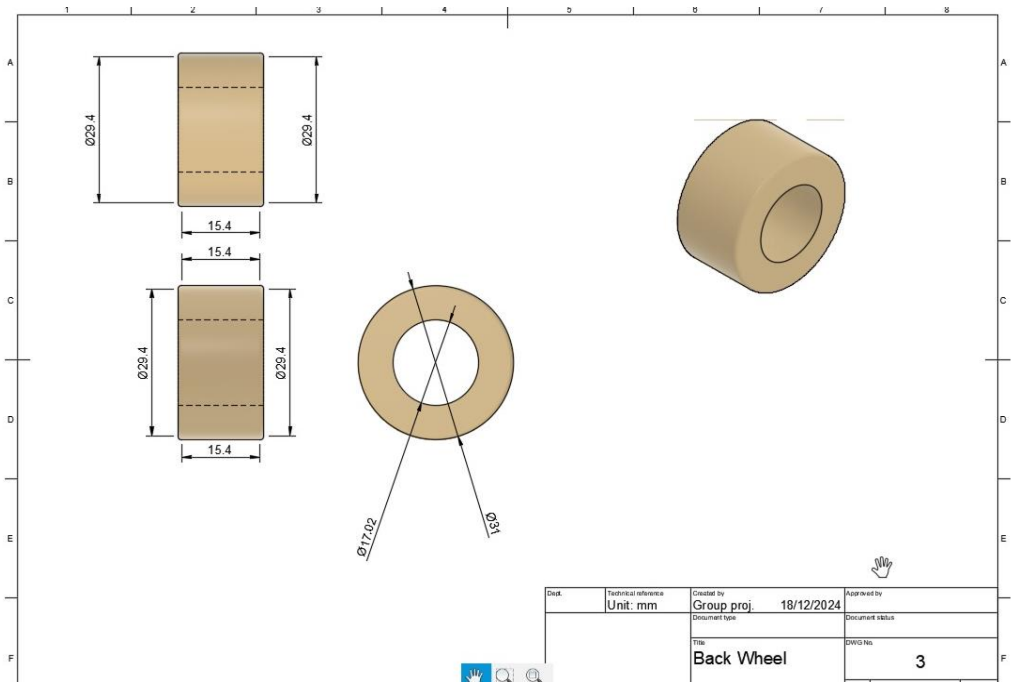

Figure 6 Back Wheel Drawing

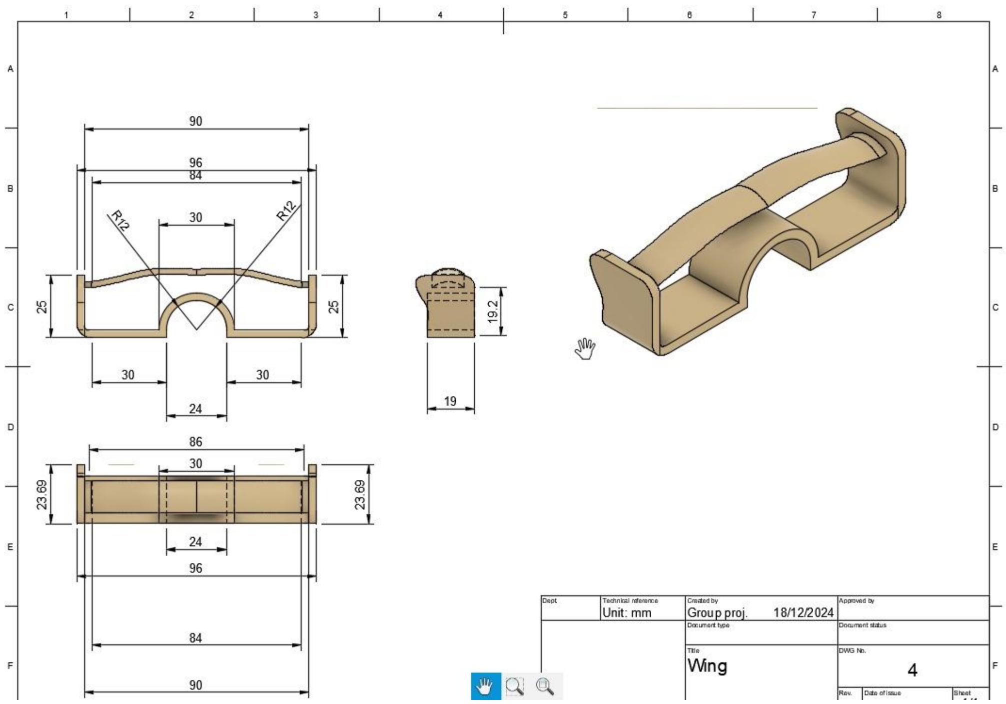

Figure 7 Wing Spoiler Drawing

4.0 Support System and Tooling

For any elaborate manufacturing process, there has to be a system to carry out all the processes required to produce the parts for assembly. In this section, all the necessary equipment, manufacturing practices and layout of the production facility shall be discussed. This allows for a more informed estimation of the expected cost of manufacturing the F1 School Car.

4.1 Production Practices and Approaches

In order to optimize the production process, a strategy is implemented to ensure the best workflow and material handling. This is often done by undergoing Systematic Layout Planning (SLP). This approach is one whereby the available space, process flow sequence and relations and dependencies between different activities in the manufacturing facility is taken into consideration in designing the layout of the process stations. This not only allows for a streamlined production process but also results in an efficient and scalable layout. [7]

Optimizing the flow of material throughout the manufacturing process is a crucial aspect in Design for Additive Manufacturing (DFAM). This can be achieved by introducing additional steps in the design process that will ensure a much faster SLA printing time and much less waste of PETG resin, which is an expensive resource compared to the rest of cost contributions. Moreover, choosing a facility layout focuses on minimizing wasted motion of the employees or the production parts results in the optimum manufacturing efficiency of the facility. [8]

Combining Industry 5.0 technologies - Additive Manufacturing, Industrial Automation and IoT Monitoring - into a single manufacturing process system significantly raises the ceiling of production's resulting quality, efficiency and economical factor. In addition, quality and dimension precision inspection procedures are to be implemented and incorporated as the final checkpoints of the manufacturing process. This is especially crucial considering the environmental requirements that SLA printing demands.

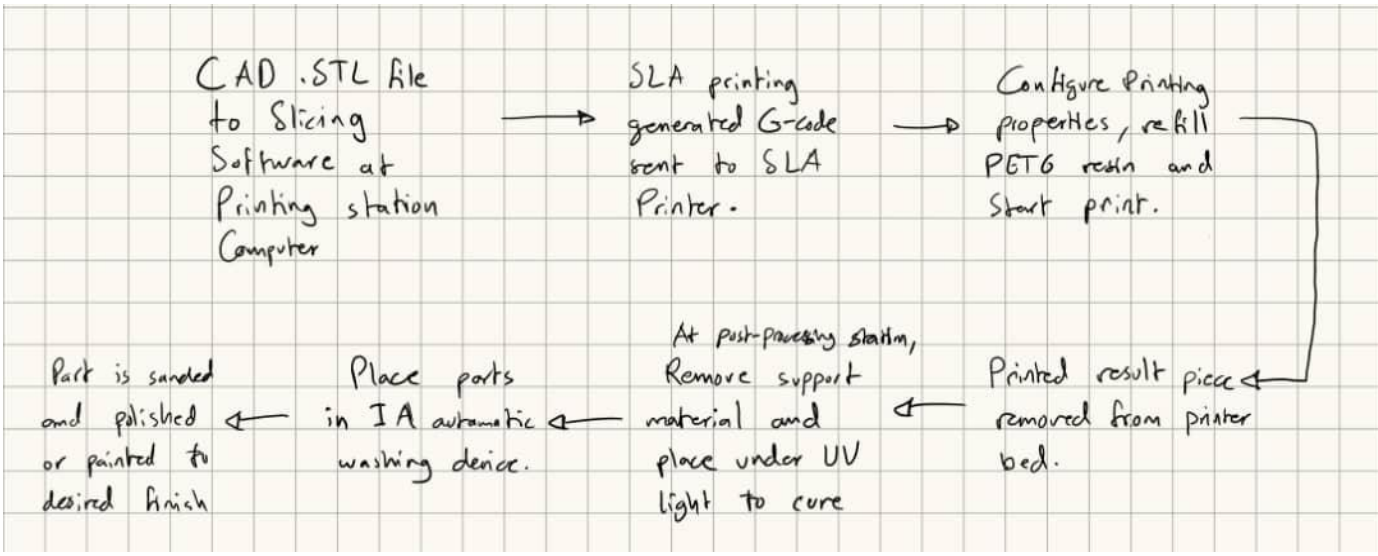

Figure 8 SLA AM process from CAD model to finish part.

4.2 Equipment

Industrial grade SLA printers shall be considered the core of the manufacturing process. This level of high-performance, high-precision printers will be more multiple folds more suitable for producing a high volume of products efficiently and of high quality. Such printers for instance, (Formlabs SLA Industrial Printers), often include more advanced features compared to desktop SLA printers, such as multi-material printing, special material support, and much higher resolution (smaller minimum layer thickness). However, considering the product being produced, this approach seems to be overkill and only further increases the cost of production.

It has to be considered that the product being produced is only made for the youth as a learning toy model. This justifies a reasonable compromise in accuracy for the sake of cost effectiveness and lower initial investment cost into the manufacturing facility. Therefore, using a small fleet of desktop SLA printers should be sufficient for this manufacturing process as it results in acceptable precision, and since all the 3D printed car parts are made of a single material (PETG resin), no multi-material printing is required, and its small size allows for multiple models production in a single print run.

Post processing stations are necessary for removing the print supports, Isopropyl alcohol or tripropylene glycol monomethyl ether (TPM) washing to remove excess resin (done manually or automated), curing (to solidify and strengthen the chemical bond inside the printed part) and finishing (painting, etc…). Furthermore, as previously mentioned, quality and dimension precision testing procedures should be implemented; hence the facility must include the necessary stations at the appropriate locations to integrate into the streamlined manufacturing process flow.

The integration of raw material (PETG resin) and waste management (automated) systems is crucial. Appropriate storing containers shall be used for keeping raw material always in stock. Waste PETG resin parts (such as support material) can be stored for recycling into PETG filament for FDM printing, which increases the sustainability of the facility. Conveyer belts and automation machines would cover this side of the process to support the production process flow. [9]

Table 1 SLA Printing Facility BOM.

Equipment Description	Quantity
Formlabs Desktop SLA Printing Machine	4
High-spec Desktop Computer Set-up	2
Low Storage Cabinet	2
200cm*80cm table (Support Removal & Curing Station)	1
120cm*60cm flat-calibrated table (Dimension & Quality Testing Station)	1
5 Layer Shelf Stand Table (Waste Material Storage)	1
Post-processing and Dimension Testing toolkit	1
Conveyor Belt Assembly (Automated Waste Management)	1
UV Light Enclosure Device (Curing Compartment)	1
ISA (Isopropyl Alcohol) Print Washing Device	4

4.3 Facility Layout

The adopted layout shape for this SLA printing is a U-shaped design as it is found to drastically reduce wasted motion around the facility and maintains a straightforward process flow route. In addition, a multi-layer operation platform can be set up in the case of challenging space constraints. This allows the facility to achieve high production efficiency with minimal area utilization for each operation zone. [10, 11]

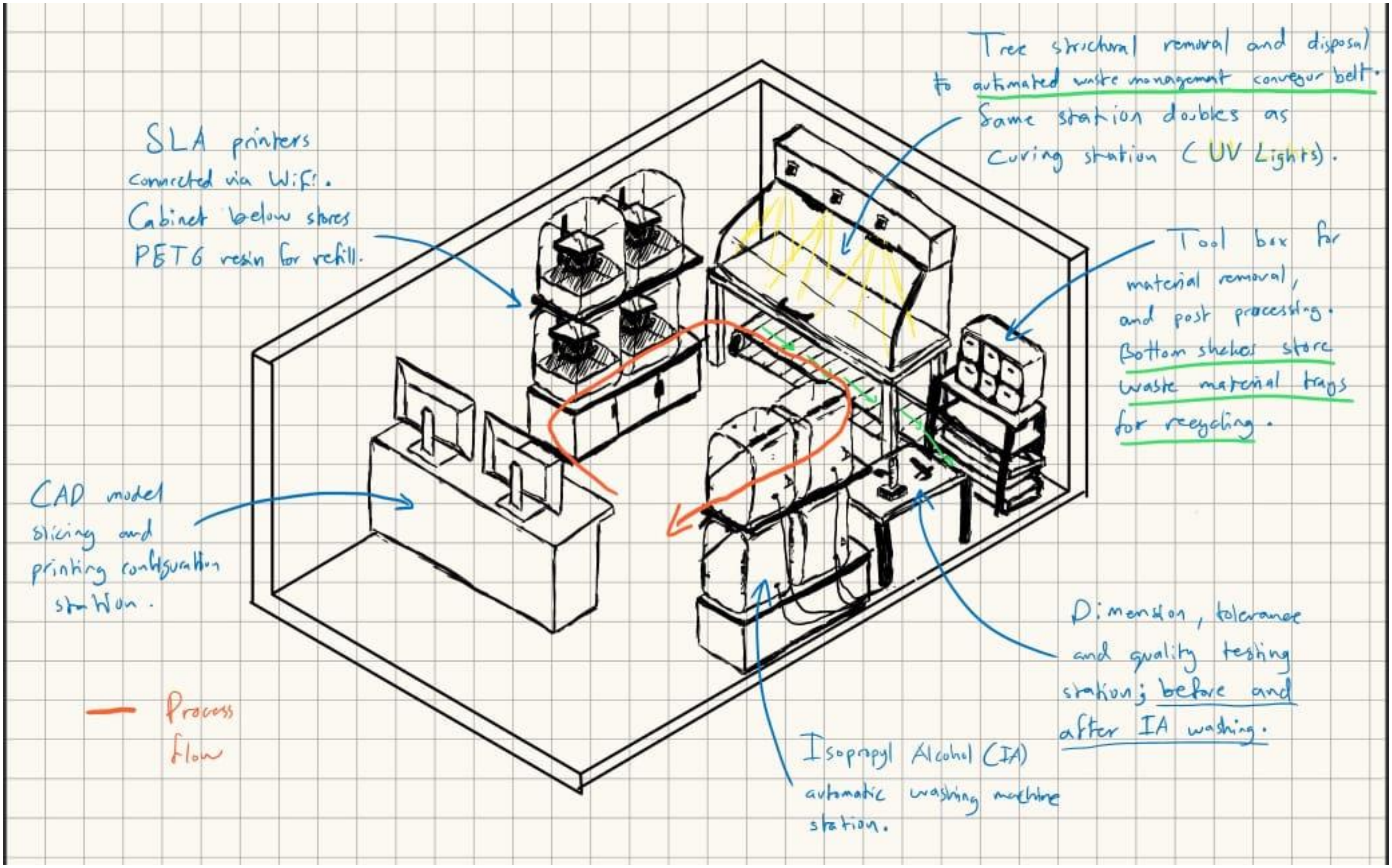

Figure 9 SLA additive manufacturing facility layout labelled sketch.

5.0 Costs

In the F1Schools car project, costs can be attributed to four broad stages: design, printing, analysis, and post-processing. Each of these stages includes several factors contributing toward budget estimation, with some having direct costs while others might involve indirect costs.

5.1 Design Cost

Since Autodesk Fusion 360 is free for personal use, there were no direct software costs for the design phase of the F1School car. This was a great cost advantage, considering its features such as modeling and simulation. However, indirect costs are involved, such as the time spent learning the software and designing the car, as well as the computer hardware used for designing the car. Efficient designs minimize material waste and can reduce costs in printing and manufacturing. As far as parts are concerned, the car has five components: halo, body, front and rear wings, and the two front and back wheels. Although the design was free, the major cost drivers in this phase come from 3D printing and assembly components.

5.2 Printing Cost

The F1School car was optimized for cost efficiency in the printing process, especially due to the resources available at UTM. PETG-like resin was used as the primary material for 3D printing. It was selected because it had a good balance between durability and performance. PETG-like is a popular material for 3D printing due to its strength, heat resistance, and ability to produce parts that can withstand mechanical stress, making it ideal for components such as the car's wings, body, and wheels. Because the printing were done within UTM, the process itself did not incur any direct costs. This kept the overall cost of printing relatively low. However, since the material was used efficiently and only the necessary amount was consumed, the cost remained minimal. Additionally, the absence of external printing fees ensured that the project's budget was kept under control.

5.3 *Analysis cost*

Ansys discovery was used to analyze the flow around the car, which easily saved license costs. Aerodynamic simulations of the car were conducted without any direct costs. Although CFD software is costly, with the aid of trial versions, the best possible design of the car for performance could be obtained without resultant costs. The principal investment was the hours spent running simulations and optimizing the design based on outcomes. After completing the analysis using Ansys Discovery, the F1School car was taken into real testing in the UTM Aero lab wind tunnel. Without external costs real validation was acquired. By utilizing UTM equipment and the demo version the expenses for assessment and testing remained low.

5.4 *Post-processing cost*

Additional components and adjustments to finalize the F1 in Schools car. A metal rod was purchased for the car shaft, along with a bearing to connect the wheels. Assembly required epoxy steel and epoxy hardener, while painting was done using available colors from the lab, which avoided extra costs. The adjustments were made due to the inaccuracies of the 3D printer; the stand drill had to be used to enlarge the shaft holes. These minor costs and resourceful use of lab materials kept the post-processing expenses minimal while ensuring the car's functionality.

The F1School car developed during this work represents a well-balanced solution with regard to cost efficiency and high performance. The employment of trial software, like Autodesk Fusion 360 and Ansys Discovery, and the resources at UTM for 3D printing and testing have allowed the work to be done without incurring major direct costs while achieving professional-level outcomes. Table 1 outlines the project's direct costs. As can be seen the total direct cost of the project was added to RM 209. The careful selection of resin PETG-like helped obtain efficiency in printing cost. The resourceful methods of post-processing also made sure functionality was attained without significant expenditure. While the design phase had indirect costs in terms of time and hardware use, the ability to optimize the car's design, minimize material waste, and utilize free resources resulted in a cost-efficient workflow. The practical testing in UTM Aero lab's wind tunnel added the real-world validation to complement the simulation analyses in solidifying the performance of the car.

Table 2 Cost of Prototype Development

Item/ component		Quantity x Size/ Weight	Total cost RM
Softwares	*Auto Desk Fusion 360 Software*	-	RM 0
	Ansys Discovery Software	-	RM 0
Material	*PETG-like resin*	1 pc x 1kg	RM 149
	Stainless steel rod/s	1 pc x 1m	RM 9
	Epoxy Steel	1 pc	RM 7
	Epoxy harden	1 pc	RM 7
	Bearings	8 pcs x 606zz	RM 34
Printing Cost	*SLA Printing with PETG Resin*	-	RM 0
Design Cost	*CAD Modelling and Topology Testing (DFAM) (In-House)*	-	RM 0
Analysis Cost	*Printing Feasibility and Structural Analysis (Design Lab UTM)*	-	RM 0
Additional Processes	*Aerodynamic Wind tunnel test (UTM)*	-	RM 0
	Other Post processes (Drilling etc..)	-	RM 0
Total Cost			RM 209

6.0 Functional Prototype

Figure 10 AM Functional Prototype for F1School Car

6.1 Aerodynamic Testing

Figure 11 UTM Wind Tunnel Aerodynamic Testing

Once the prototype was finalized and printed, it needed to be aerodynamically tested to ensure its performance in the F1Schools car program. Hence, as illustrated in figure 11 above, the printed prototype was tested using UTM's wind tunnel facility. Primarily, the objective of the aerodynamic test is to calculate the lift to drag ratio—In particular, a higher lift to drag ratio correlates to a better aerodynamic car. It means that the car produces significant downforce (lift) with minimal drag, improving stability at high speeds.

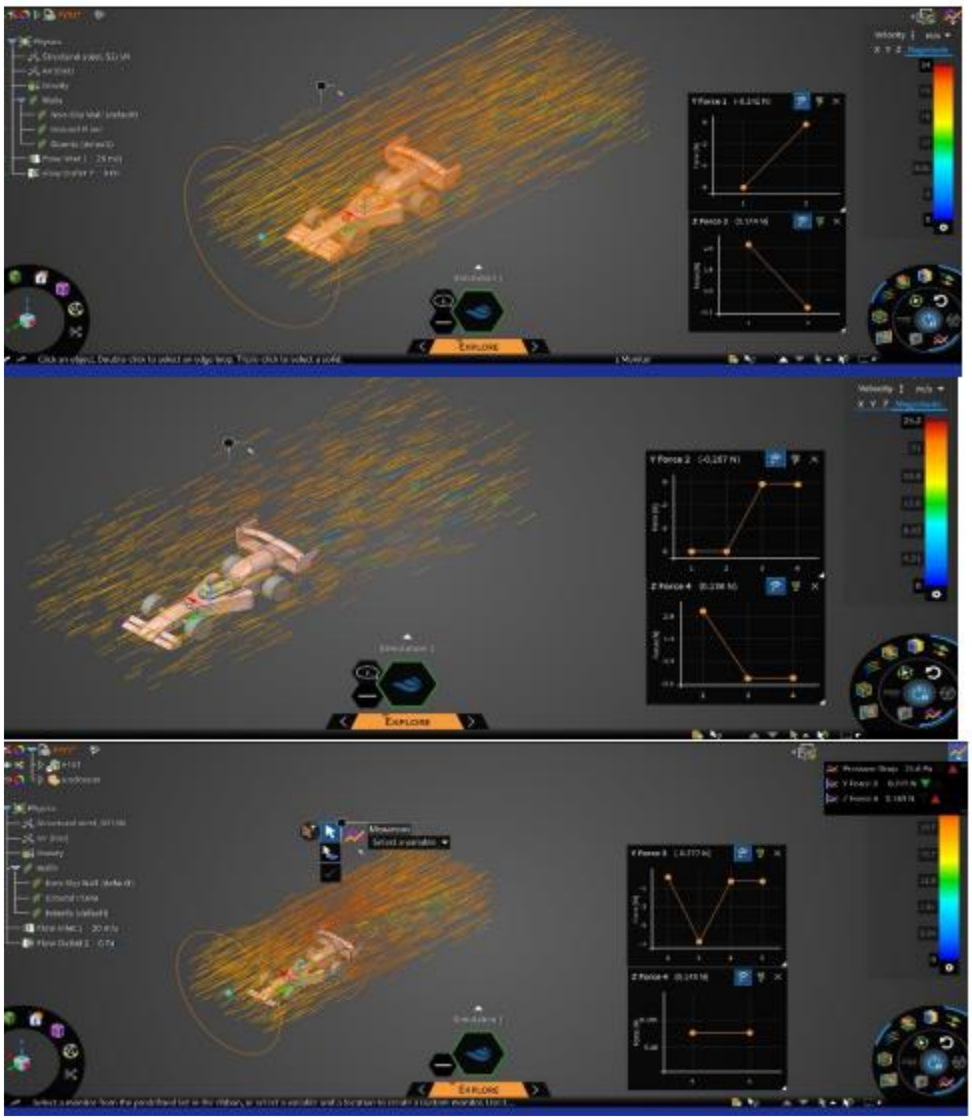

Figure 12 Wind Tunnel Testing Interface

As shown in the figure above, the car was tested with different speed configurations and the data was tabulated for analysis

Table 3 Pressure and Forces acting on the Car

Velocity	Pressure	Fx	Fy	Fz
30 m/s	526 Pa	0.045891 N	1.279387 N	-0.34055 N
25 m/s	365 Pa	0.046387 N	0.90771 N	-0.13661 N

Table 4 Moment Acting on the Car

Velocity	Mx	My	Mz
30 m/s	0.192774 Nm	-0.15461 Nm	-0.21261 Nm
25 m/s	0.169226 Nm	-0.1291 Nm	-0.17035 Nm

Hence, utilizing the data tabulated in table 3 and table 4, the lift to drag ratio for the prototype was calculated to be 15% and 26.6% for Velocity (25 m/s) and (30 m/s) respectively. The data yields that the car has a good balance of drag reduction and stability, indicating its successful design for a competitive F1Schools program which requires aerodynamic efficiency.

6.2 *Design for Additive Manufacturing (DFAM)*

Considering the type of additive manufacturing chosen is pivotal in the design process to result in a performance optimized, weight efficient and economical 3D printed part. A method that achieves that while maintaining the part's strength and rigidity is topological optimization. This process involves the utilization of simulation software (possibly an extension of the CAD modelling software, such as SolidWorks) to determine the places where material is not required by avoiding the areas of stress concentration and preserving required geometry, such as the faces where the part assembles and aerodynamically optimized surfaces.

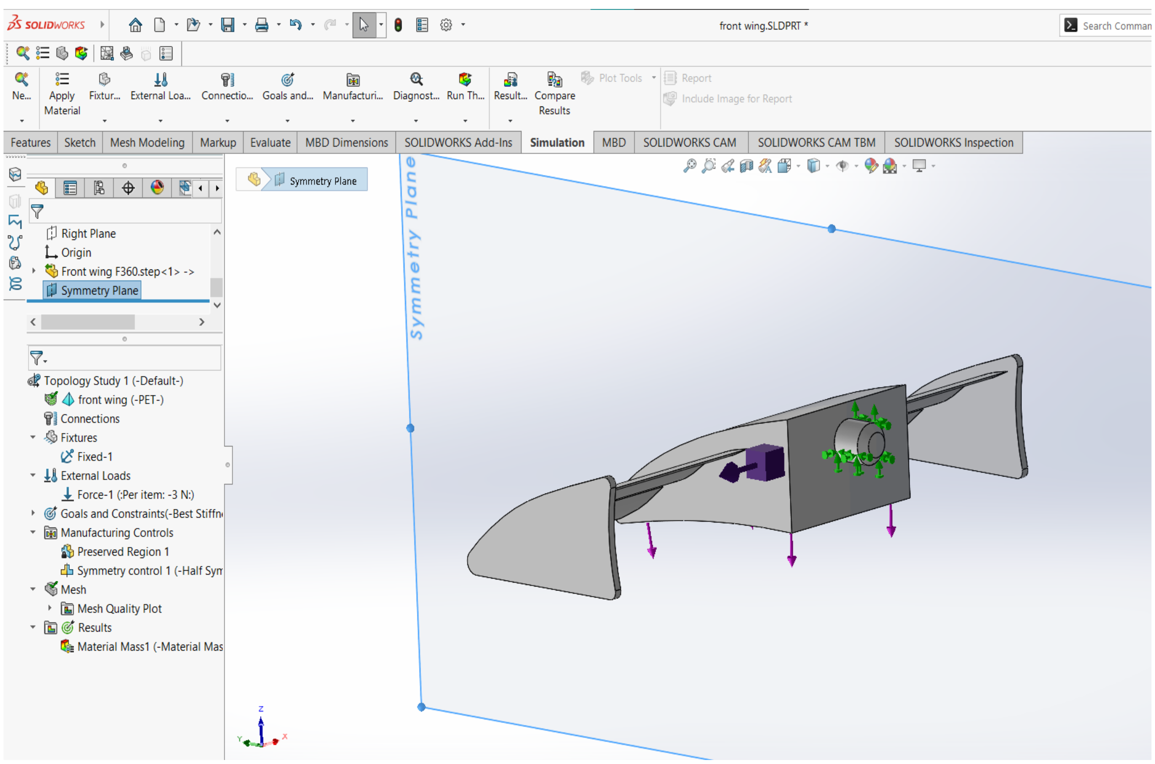

Figure 13 Car Nose Model Topology

As illustrated in the figure above, on this design, the car's nose part holding the front winglets was optimized using the topology study feature in SolidWorks Simulation Premium. The relevant expected forces accounted for a minimum safety factor of 2 were applied. To preserve the mounting extrusion and the aerodynamic top surface of the nose with the winglets on either side, these surfaces were selected and a 1mm offset was chosen to account for errors in the topological optimization study. The goal for this study was set to achieve the best stiffness to weight ratio while reducing the part's weight by 50 percent.

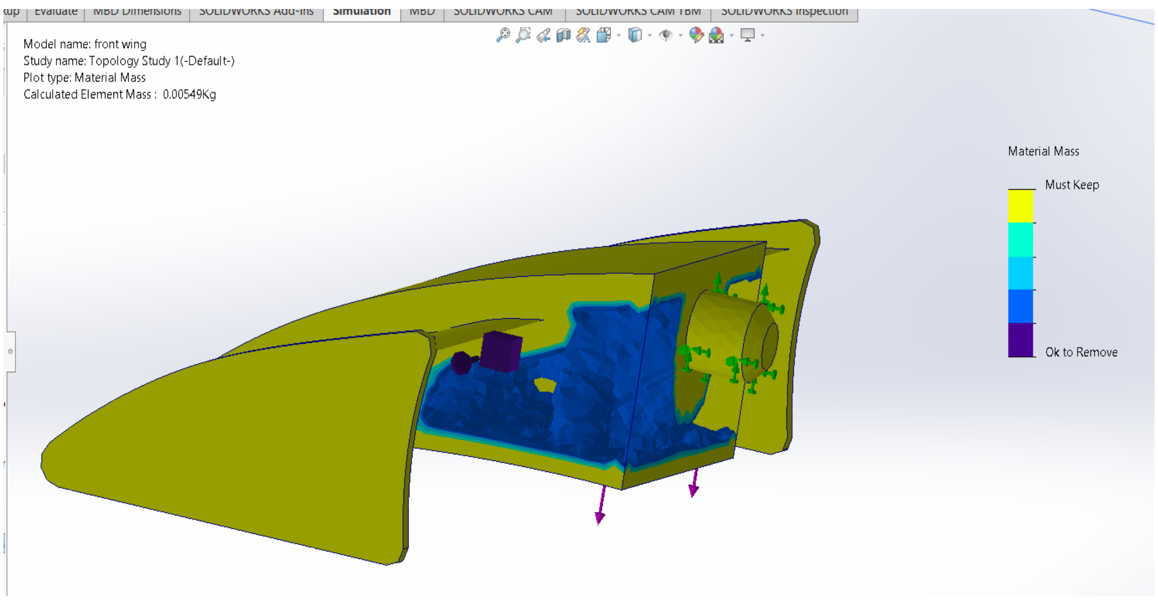

Figure 14 Optimized Part Through Topology

The resulting topologically optimized mapped part resulted in an informed shelling of the nose part. The part was bound to stay symmetrical at the YZ plane to maintain consistency. Finally, a smoothed body mesh was exported to be saved as a topologically optimized Car Nose .STL part - prepared to be SLA printed.

This process takes advantage of the superiority of SLA in printing complex parts. Topological Optimization has certainly proven to be an effective and efficient method for DFAM that results in a lower cost of production due to reduced material usage, printing time and maintained or improved product performance.

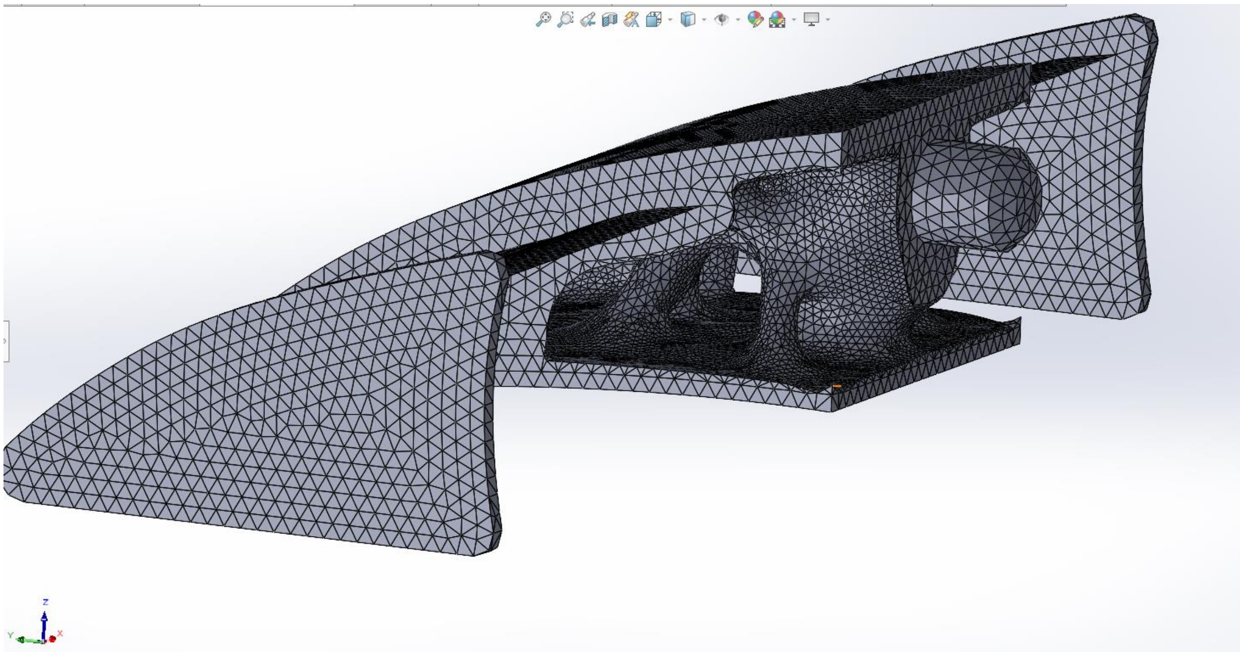

Figure 15 SLA Part to be Printed

The figure above illustrates the final Car Nose optimized part to be printed using SLA (Stereolithography).

7.0 Discussion

Educators utilize Additive Manufacturing in the "F1 in Schools" model car program to prove how new technology methods improve educational outcomes and environmental preservation. Our study investigates AM manufacturing used in model cars to show how it benefits technical work while saving money and helping the planet while educating young people in STEM subjects.

1. Innovative Design and Additive Manufacturing

The main advantage of additive manufacturing helps us transform how products are designed. Manufacturing traditional model wheels and airfoil shapes requires several steps at high material usage. With AM designers can produce exact physical models from their digital designs right away.

By using SLA Stereolithography technology, the vehicle creators produced detailed aerodynamic parts smoothly without excessive subsequent processing. Engineers decided to use PETG for elements that had to withstand collisions to demonstrate how choosing materials in additive manufacturing aligns with functional demands. Adding SLA and PETG materials demonstrates that AM technology lets you pick the right materials without giving up quality results.

2. Lower Costs and Reduced Material Waste

The traditional production system produces large amounts of waste when making parts through the subtractive process. Additive manufacturing produces excellent results by building individual product layers that waste very little material. By precisely controlling material deposition the F1 in Schools team used less PETG resin which lowered costs and benefited the environment.

Rerouted PETG waste from the production process yields new FDM printing filaments that enable both cost savings and environmental protection. This cycle helps manage waste and evokes eco-friendly manufacturing methods which STEM students must learn through their education.

3. Accessibility and Reduced Design Cost

Hybrid SLA technology gives us advanced printing potential, yet our selection of basic printers was both useful and budget friendly. The classroom SLA printer met teaching goals and saved money because it produced precise models without needing professional SLA printers. Students could use Autodesk Fusion 360 without charge because it was available for free personal use to save design expenses.

The project showed that students can learn advanced manufacturing at lower cost with desktop printers to create excellent projects. The project shows the true potential of AM for school programs through its low spending requirements.

4. Skill Development and Educational Outcome

By adding AM to the F1 in Schools project students gained practical experience with these advanced manufacturing tools while building their knowledge of CAD design selection and production improvements. Students began using Design for Additive Manufacturing principles to design components that utilize AM features including less support material and proper build placement.

The project adopted a clear manufacturing process by using Systematic Layout Planning to plan production areas and implement quality management methods. Students learn professional manufacturing techniques that help them enter engineering and manufacturing fields.

5. Challenges and Solutions

Although AM delivers many benefits our team experienced technical hurdles when deploying it. For optimal results in SLA printing people need to control and watch the part environment because this process reacts strongly to external changes. Secondary production steps including washing and curing processes made the manufacturing procedure more difficult to achieve the wanted outcome and product strength.

Our research discovered that setting out specific targets for both outcomes and expenses is essential. Our choice to use desktop printers over industrial-grade equipment showed that basic cost-effective tools can successfully help students learn important subject matter. These difficulties required leaders to create effective AM technology strategies and choices

6. Sustainable Manufacturing

Through its AM integration the F1 in Schools program boosted its production output while producing superior quality results and supported environmental conservation. The new production methods save materials and conserve energy while using waste-free materials which help build sustainable manufacturing globally. When students learn these sustainable methods they become more responsible and creative in their future work.

AM's power to make lightweight performance matches progress achieved in both aerospace and automotive engineering fields. When students use education in real-world applications they can better see how STEM subjects relate to reality and find learning more interesting.

8.0 Conclusion

Overall, using additive manufacturing technologies for "F1 in Schools" revisited the need to use sustainable and easy to use modern manufacturing methods beyond the industry. Integrating AM processes in education builds a solid foundation for future generations, which can be used to propagate further growth in industry and manufacturing sectors. Though traditional production methods are successful, Additive Manufacturing methods can revolutionize education. Exposing the younger generation to this technology early on enables them to critically analyze its pros and cons. Particularly, this case study revolves around F1Schools car, an educational tool for STEM students that provides hands on experience with electronics and 3D design. However, as discussed, this design was manufactured through traditional methods such as CNC machining or carving. This project proposed the use of SLA and PETG materials to create an accurate and aerodynamic car design that met all competition standards at lower manufacturing costs while minimizing waste.

By integrating AM into the F1Schoosl program, students learn about the importance of sustainable design practices, the need for accurate material selection, and the application of additive manufacturing methods. AM integration in this study shows how engineering programs need to advance to serve real-world industry needs by developing creative student minds.

Hence, as illustrated in figure 10, this project successfully manufactured a working F1School car prototype through Vat Photopolymerization utilizing SLA (Stereolithography). The prototype produced was structurally sound and aerodynamically viable to compete in the F1School program. Furthermore, the results indicated that despite being produced at a lower cost, its performance was not significantly impacted.

In conclusion, this project accomplished its primary objective of producing a prototype for F1Schools Car using AM processes. The prototype had an effective aerodynamic design verified through testing, geometry optimized through DFAM using topology testing, was able to utilize modular wing profiles, and had reduced costs as compared to traditional manufacturing methods. Thus, it creates a model for future work that shows how engineering must combine technological achievements with affordable solutions that care for the environment, suggesting that through integrating AM manufacturing "F1 in Schools" students experience modern engineering principles more effectively than traditional classroom teaching.

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