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Segmented Printing Strategies for Reducing Support Structures in an F1 Rear Wing

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Abstract. This study explores the use of segmented printing to optimize support structures in the fabrication of a Formula 1 rear wing mold through Fused Deposition Modeling (FDM). Conventional molds for Carbon Fiber Reinforced Polymer (CFRP) components are produced by CNC machining, which delivers accuracy but involves high cost, long preparation times, and limited flexibility for complex surfaces. To investigate a more accessible alternative, a rear wing model inspired by 2011 Formula One regulations was created in Autodesk Fusion 360, incorporating the main plane, flap, and endplates. The outer mold was divided into six segments, with orientations selected to minimize overhangs and reduce the need for support material. Slicing previews were used to estimate support requirements and evaluate printability. Results indicate that segmentation enables a substantial reduction in support volume, improves post-processing accessibility, and ensures compatibility with standard printer dimensions. Although physical printing was not performed, the analysis demonstrates that segmented molds could provide a cost-efficient and practical approach to CFRP layup. This design-based method highlights how segmentation can enhance additive manufacturing efficiency, offering potential applications in motorsport prototyping and other fields requiring lightweight, geometrically complex tooling.

Keywords: 3D Printing, Formula One, Rear Wing, Segmented Printing

1. Introduction

As the top-level car racing event in the world, Formula One (F1) racing is hailed as a “mobile technology laboratory”. Since the 1970s, F1 has undergone dramatic advancements in performance. The demands on strength, rigidity, and aerodynamic stability became stricter and higher as the speed of racing cars increased.

The rear wing is a core component that affects the aerodynamic performance of the racing car, characterized by a complex geometric shape and numerous curved surfaces. It is also the part that is iterated most frequently in the design of racing cars. The front and rear spoilers in F1 play a key aerodynamic role by altering the path of surrounding airflow and producing downforce, thereby enhancing tire grip and vehicle performance. Roughly a third of the car's total downforce comes from the rear wing assembly, which varies based on the track's requirements [1].

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Carbon fibre reinforced polymer (CFRP) has some good characteristics, including low density, high stiffness and modulus [2]. CFRP can offer up to ten times higher strength than metals such as aluminium and steel. Therefore, CFRP is an ideal material for lightweight and high-performance applications. It became a dominant material used in F1 critical aerodynamic components, particularly in rear wings, to realize a reduction in weight and maximization of stiffness [3].

Computer numerical control (CNC) machining is one of the most adopted manufacturing techniques in the production of CFRP aerodynamic components. In the process of producing the F1 rear wing, CNC milling is typically used to fabricate the female mold, which could cure carbon fiber laminates into precise aerodynamic profiles. This process offers high-dimensional accuracy and surface finish. However, CNC machining often requires extensive material removal from solid blocks, which leads to high material waste and cost, especially for large molds [4]. Additionally, the toolpath planning for intricate geometries can be time-consuming. Besides, production is limited to subtractive capabilities, which would also restrict design freedom. These limitations have motivated research into additive alternatives to reduce material use and improve support structure efficiency.

The application of additive manufacturing in the production of aerodynamic parts is increasing. Fused deposition modeling (FDM) has been explored for polymeric aerofoil fabrication. Recent studies show that researchers have printed NACA-series aerofoil models by using PLA-based filaments and tested aerodynamic performance in wind tunnels. It also finds that the roughness of the surface critically affects lift and drag behavior [5]. Adapting FDM for high-temperature polymers or polymer-metal composite filaments may enable lightweight aerodynamic components in motorsport applications.

This study investigates the optimization of support structures through segmented printing of an F1 rear wing using fused deposition modeling. A digital model of the rear wing and its female mold was developed in Fusion 360. This research uses a low-cost and rapid prototyping approach via additive manufacturing, rather than using conventional CNC tooling. The segmentation strategy was proposed to minimize support material. The estimations of support volumes and orientations were supplied based on published references, although algorithmic simulations were not employed. This study of 3D printing of F1 rear wing models would contribute to the evolution of advanced manufacturing in motorsport. In the long term, it may also provide valuable reference for other industries that regard the ratio of strength and weight as important, such as aerospace and national defense [6].

2. Literature review

2.1. Progress in additive manufacturing

Additive manufacturing (AM) is increasingly important in motorsport prototyping and tooling. It offers rapid iteration cycles and geometric freedom that surpasses traditional subtractive methods like CNC milling. Fused deposition modeling (FDM) has high accessibility and material versatility; therefore, it has gained traction for producing aerodynamic parts and molds.

In wind tunnel research, FDM has been used to fabricate full-scale NACA aerofoils. The experiments confirm the impact of print layer orientation and surface roughness on drag and lift characteristics [5]. The post-preprocessing method can be used to mitigate surface defects, such as acetone smoothing or surface ironing.

In motorsport, Red Bull and Ferrari teams have already integrated AM into their development pipelines. They use selective laser sintering (SLS) and FDM to produce various components during pre-season development, which include brackets, ducts, and some other aerodynamic parts [7].

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However, limitations remain: FDM is generally constrained to thermoplastics, and its layer-based nature introduces anisotropy in mechanical strength. Nevertheless, efforts are underway to adapt high-performance polymers such as PEEK or ULTEM for structural FDM applications, aiming to replicate the mechanical properties of CFRP-based parts while simplifying the fabrication process.

2.2. Segmented printing technology

Segmented printing—or partition-based printing—is a technique where a complex 3D model is divided into smaller, more printable components to reduce support structures, improve surface quality, and optimize build orientation. It is particularly useful for large or intricately shaped objects, such as the F1 rear wing, where overhangs and thin walls pose significant manufacturing challenges [8].

Research in this area has introduced geometric partitioning methods based on principal build directions and support volume minimization. For example, models can be sliced along curvature-adapted planes to align outer surfaces with the build platform, drastically reducing the required support material. According to Rapid Prototyping Journal, there is up to 60% reduction in support volume using segmentation, compared to conventional Z-direction slicing.

In the case of FDM, segmentation also helps mitigate warping and delamination by reducing thermal stress concentrations in large single prints. For practical applications, alignment features such as notches or dowels are embedded in each segment to ensure post-print assembly accuracy.

Thus, segmentation enables the effective manufacturing of geometrically complex aerodynamic components and aligns well with the lightweight, high-efficiency goals of motorsport prototyping.

2.3. Challenges and opportunities

Despite its advantages, additive manufacturing for motorsport applications faces several challenges. First, support structure removal can be tedious and damaging, especially on internal surfaces or narrow cavities. This makes support optimization a critical step in design for additive manufacturing [9].

Second, while segmentation helps reduce support dependency, it introduces new challenges in part alignment, joint strength, and post-processing accuracy. Current research in generative segmentation algorithms and curved-layer deposition could mitigate some of these issues in the future.

Nonetheless, opportunities are vast. AM enables functional prototyping, distributed manufacturing, and rapid aerodynamic testing cycles. When combined with simulation tools and topology optimization, it holds the potential to transform how high-performance racing components are designed and manufactured [10].

3. Methodology

The research is structured as a design-driven case study. It puts emphasis on practical constraints in additive manufacturing, such as support volume, print orientation, and build time. The main goal is to achieve minimization of material wastes, printing time, and the use of support structures while preserving the shape of the wing.

This chapter outlines the approach adopted for investigating and optimizing segmentation strategies and support structures in the FDM 3D printing of an F1 rear wing prototype. The rear wing was modeled in Fusion 360, drawing inspiration from 2011 F1 designs. The geometry was

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divided into segments to reduce overhangs and improve print efficiency. Algorithmic simulations were not applied, but data estimation techniques supported the design process. The method offers insights for motorsport prototyping and may also apply to fields such as aerospace and robotics.

3.1. CAD modeling of a rear wing in Fusion 360

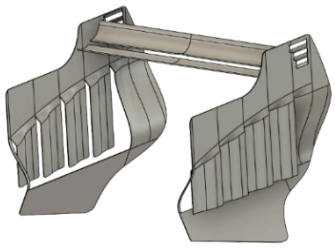

Figure 1. Isometric view (front) of rear wing model

The rear wing model was developed in Autodesk Fusion 360 with a design-driven approach to balance aerodynamic performance and manufacturability. Inspired by typical Formula 1 configurations, it integrates the main plane, flap, and endplates, with careful attention to curvature and surface continuity to reduce flow separation and drag. Figure 1 shows the front isometric view of the model, while Figure 2 shows other views of the rear wing. Figure 3 shows all the elements' names. These visualizations form the basis for later analysis of segmentation strategies and support optimization in 3D printing.

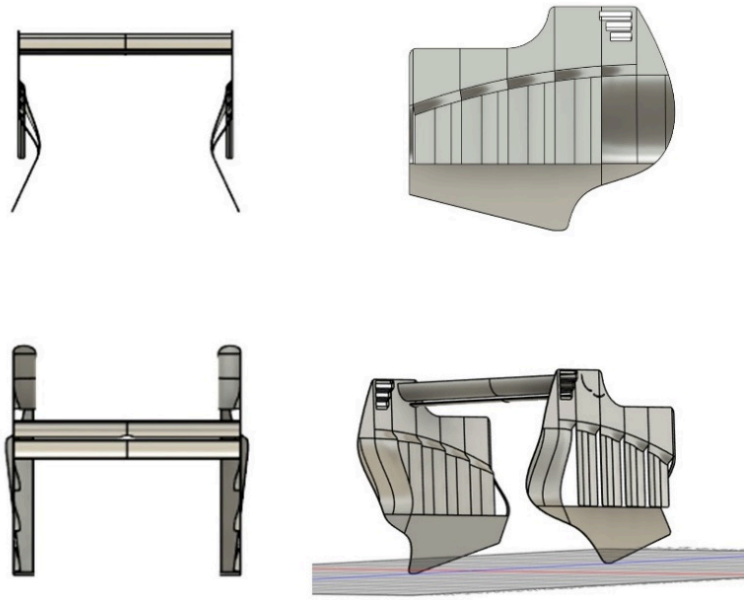

Figure 2. Different views of rear wing model

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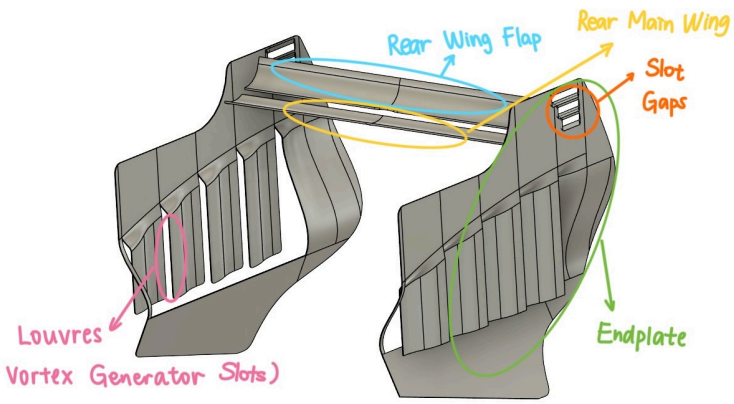

Figure 3. Elements' names

In addition to modeling the aerodynamic part itself, a corresponding female mold, as shown in Figure 4 was created in Fusion 360 to facilitate FDM-based manufacturing. The mold geometry was generated by offsetting the outer surfaces of the rear wing model by 2.5 mm, accounting for the wall thickness commonly used in thermoplastic tooling. Boolean subtraction was applied to hollow out the mold cavity precisely around the rear wing profile, ensuring dimensional compatibility and curvature preservation.

To support the segmented printing strategy, the mold was also divided into six parts, aligned with the segmentation lines of the rear wing model. Each mold segment was designed with flat bases to improve bed adhesion and minimize the need for supports during the printing process. Small alignment features such as interlocking notches or dowel holes were included at the edges of adjacent segments to ensure proper assembly post-printing.

This mold design serves both as a functional tool for potential composite lay-up and as a platform for analyzing support structure requirements under realistic additive manufacturing constraints.

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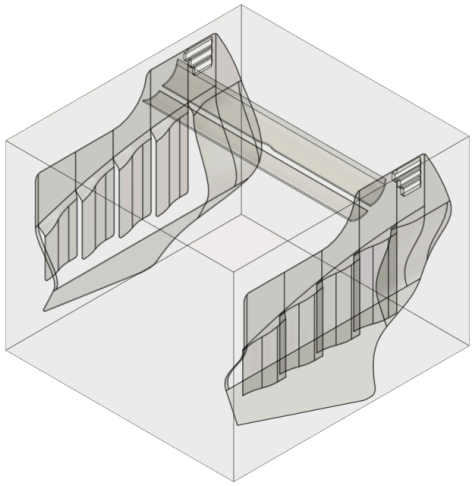

Figure 4. Rear wing female mold

3.2. Assumptions of rear wing parameters

Given the limitations in physical prototyping, this study relies on analytical estimation rather than empirical validation. The rear wing and its female mold were modeled according to the 2011 Formula One Technical Regulations. The design parameters of the rear wing were shown in Table 1 below.

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Table 1. Rear wing design parameters [11]

Component	Parameter	Value
Overall Wing	Overall Width	1650 mm
	Overall Height	900 mm
	Fore-aft Depth	300 mm
Mainplane	Chord Length	250 mm
	Span	1650 mm
	Max Thickness	20 mm
Flap (incl. DRS)	Chord Length	100mm
	Gap to Mainplane	15 mm
Endplates	Height	350 mm
	Length	350 mm
	Thickness	7 mm
	Slot Gaps	4 slots
Material & Process	Material	CFRP
	Manufacturing	FDM outer shell

3.3. Segmentation strategies and support structure estimation

To reduce support structures and material usage, the wing model was segmented into six parts based on geometry and print orientation considerations, as shown in Figure 5. Segments 1 and 2 (the flap and main wing) are printed horizontally, where both curved surfaces face upward, minimizing overhangs. Endplates were split vertically into segments 3–6, aligning the rib-like features and reducing unsupported features.

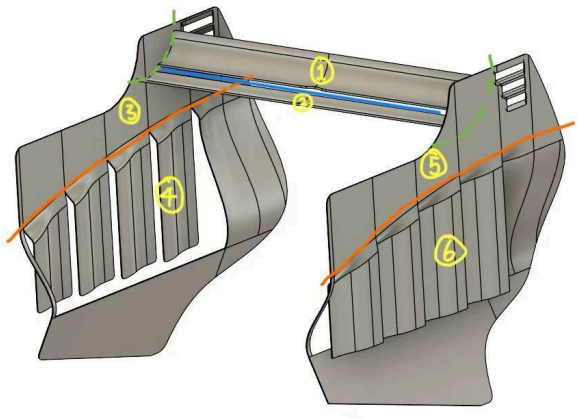

Figure 5. Segmentation

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The segmentation lines were selected to ensure most sub-surfaces stay within the printable overhang threshold (~45°). However, slight support may still be required for inward curves in segments 4 and 6. These support zones were verified through slicing preview tools.

This segmentation strategy improves printability, reduces reprint risk in case of local failures, and allows efficient build plate arrangement. Although not generated via optimization algorithms, the manual segmentation approach proves to be effective in lowering support volume while preserving surface fidelity.

4. Analysis and discussion

4.1. Benefits of the proposed design

The proposed segmented printing approach for the rear wing mold provides several advantages over conventional single-piece FDM printing or CNC-based mold manufacturing. First, the partitioning strategy significantly reduces the reliance on support structures. According to the findings of Demir, the near-convex decomposition of models can save approximately 32% of support material and shorten printing time by 34% [12]. The segmentation in this study allows each sub-component of the rear wing to be oriented close to a flat plane, thereby minimizing support requirements and post-processing efforts. Second, the method offers design flexibility and adaptability. Jadoon et al. demonstrated the value of interactive partitioning tools for large 3D models, enabling users to split oversized components into printable parts while preserving design intent [13]. Likewise, the CAD-based manual segmentation employed here makes it possible to adapt the mold to printer build-volume limitations without compromising aerodynamic features. Third, the approach highlights the potential for further optimization through multi-directional decomposition. Wu et al. reported that beam-guided partitioning can automatically determine cutting planes to minimize overhangs and further reduce support volume [14]. Although this project applies a simpler geometric segmentation, its benefits align with these research directions by proving that dividing the rear wing mold into flat-oriented sections leads to more efficient, cost-effective, and reliable additive manufacturing.

4.2. Design limitations

Segmented printing offers clear benefits but also has limitations.

First, the method depends on manual partitioning in CAD software, without algorithmic optimization. This lowers the accuracy of both segmentation and orientation choices. As a result, certain regions may still require excess support or show reduced build quality. Previous studies indicate that algorithmic decomposition can automatically define optimal cutting planes, reducing overhangs and support volume with greater precision [14].

Second, the structural performance of the segmented mold remains uncertain. Partition interfaces may act as weak points, creating stress concentrations or reducing the overall mechanical integrity of the assembled mold. Similar concerns were noted in Formula Student rear wing bracket design, where connection points were found to be critical for load transfer [15]. Further validation is required to confirm the reliability of the segmented mold. Methods such as finite element analysis or experimental testing can verify that segmentation does not reduce the mold's functional strength.

Finally, FDM is cost-effective and suitable for prototyping. However, it offers lower dimensional accuracy and surface quality than advanced methods such as selective laser melting (SLM) or stereolithography (SLA) [10]. These limitations may restrict the industrial use of FDM-based molds, particularly in high-precision areas like Formula 1 aerodynamics.

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4.3. Future applications

The segmented FDM mold strategy has strong potential in motorsport and related industries. Additively manufactured molds have already proven effective for limited runs of fiber-reinforced composites when combined with suitable coatings [16]. In Formula Student and Formula One, applying segmented molds could accelerate the development of aerodynamic components such as rear wings or brake ducts, offering a cost-efficient alternative to CNC-based tooling [17].

In aerospace, additive manufacturing with topology optimization has produced lighter but durable structures [4]. This suggests that segmented molds for CFRP layup could help lower costs while also improving performance. With the continued expansion of carbon fibre applications across industries [3], such approaches may also provide smaller manufacturers with affordable access to advanced composites.

Future improvements are expected through integration with advanced processes. Large-format additive manufacturing with milling has been used to create composite molds of industrial quality. The use of algorithmic decomposition and generative design can further improve segmentation accuracy and scalability [14]. With these advances, segmented printing is not only a tool for prototyping but also a practical route for scalable composite tooling in high-performance sectors.

5. Conclusion

This study explored segmented printing to optimize support structures in FDM fabrication of an F1 rear wing mold. The model was divided into six parts, which reduced support use while keeping the aerodynamic surfaces accurate. This showed a practical and cost-efficient alternative to CNC tooling.

The results suggest that segmented printing is a feasible method for rapid prototyping in motorsport engineering. It offers a balance between manufacturability, material efficiency, and design flexibility. The approach also supports wider use of additive manufacturing in high-performance fields where lightweight and complex geometries are essential.

Future work should include algorithm-based decomposition and generative design to improve segmentation accuracy. Large-format additive manufacturing with post-processing could also be explored to strengthen industrial applications.

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