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Design and Flow Simulation of Resin Dispensing System for UV Laser-Based Extrusion 3D Printing Technique †

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Abstract: Stereolithography (SLA) is a 3D printing technology that uses a laser to cure liquid resin from a tank, layer by layer, to create highly detailed and precise objects. However, this 3D printing technique requires a large amount of resin material to be placed in the bath that is exposed to UV each time a layer is printed. On the other hand, extrusion 3D printing offers the printing of a part by dispensing only the desired amount of material on demand. However, extrusion 3D printing does not result in the intricate high-resolution features that can be achieved in SLA. To be able to 3D-print high-resolution parts without needing a large resin bath, a dispensing system was designed that would deposit only the required amount of resin on demand while high-resolution capability is achieved by curing the deposited resin using a UV laser. To ensure the isotropic properties of the printed parts, fluid flow simulations of the polymer resin through the designed dispensing system were performed. Therefore, the primary objectives were twofold: (1) designing a resin dispensing system including a specialized nozzle to promote laminar flow and (2) conducting fluent simulations to analyze the nozzle's performance. The fluent simulations provided valuable insights into the fluid dynamics, affirming the nozzle's efficiency in ensuring a consistent and controlled laminar flow of the resin during the dispensing process.

Keywords: additive manufacturing; 3D printing; fluid flow simulation; polymer resin; stereolithography; dispensing system

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1. Introduction

Three-dimensional (3D) printing, commonly referred to as additive manufacturing, has transformed a number of industries by facilitating the manufacturing of complex designs with high precision straight from digital blueprints. This technique has attracted considerable attention because of its adaptability, which enables the fabrication of customized components and prototypes in less time compared to standard manufacturing processes [1,2].

Out of the many 3D printing processes available, two notable methods are stereolithography (SLA) and fused deposition modeling (FDM), sometimes known as extrusion 3D printing. These technologies have certain benefits and drawbacks that set them apart [3,4].

Stereolithography (SLA) uses a laser to selectively solidify liquid resin from a container (known as a resin tank), one layer at a time, in order to produce objects of complex geometries. This process is highly proficient in creating components with smooth surfaces and intricate details, making it perfect for applications that demand features with high levels of resolution. Nevertheless, SLA generally requires a substantial amount of resin material to be maintained in the resin tank during printing. This demand not only leads to higher material consumption but also presents difficulties in effectively managing and disposing of surplus resin [5,6].

Conversely, FDM operates by pushing thermoplastic filament through a heated nozzle, gradually adding material layer by layer to construct the final object. Fused deposition modeling (FDM) provides benefits such as cost efficiency, ease of use, and the capability to print using a diverse selection of materials. In addition, FDM enables printing on demand by dispensing the exact quantity of material needed for each layer. This reduces waste and promotes the effective utilization of materials. Nevertheless, FDM sometimes faces challenges in attaining the equivalent level of intricacy and surface quality as SLA, hence making this technology less appropriate for applications that need intricate features and a high resolution [7,8].

The comparison of these two widely used 3D printing techniques emphasizes an important trade-off between the effectiveness of material usage and the ability to achieve high levels of precision. SLA is very effective in manufacturing high-resolution components, but it necessitates a substantial amount of resin [9], resulting in material wastage and posing issues in terms of management. On the other hand, FDM provides good material usage [10] but sacrifices resolution, which restricts its usefulness in specific high-precision uses.

In order to overcome these challenges and harness the benefits of both SLA and FDM, a new method is suggested. This concept entails the development of a dispensing system that can accurately deposit the necessary quantity of resin as needed, similar to FDM technology while utilizing the high-resolution capabilities of SLA technology through UV laser curing. This technology achieves resin dispensation only in necessary areas, eliminating the requirement for a sizable resin bath. As a result, it reduces material usage and waste while maintaining the ability to print with high resolution.

Creating such a dispensing system requires meticulous attention to fluid dynamics in order to guarantee accurate and regulated resin application. In order to achieve this objective, a resin dispensing system was created, which includes a unique nozzle specifically intended to enhance the smooth flow of the resin. Computational fluid dynamics simulations were performed to examine the performance of the nozzle and verify its effectiveness in providing constant and regulated resin flow during the dispensing operation.

In this paper, we present the design and flow simulation of the specially designed nozzle that is part of the resin dispensing system for UV laser-based extrusion 3D printing, aiming to overcome the limitations of traditional SLA and FDM methods and enable the fabrication of high-resolution parts with minimal material usage.

2. Methodology

The methodology consists of two parts: designing the components of the dispensing system, including the nozzle, and the simulation of the fluid flow through the nozzle.

2.1. Designing the Components of the Dispensing System

The dispensing system consists of (i) a carriage-mounted nozzle to dispense the resin on the bed, as shown in Figure 1a and (ii) a syringe pump to continuously supply the resin to the nozzle through a tube. The syringe pump and the carriage designs were adapted from [11] under CC BY-SA. The carriage is mounted on a lead screw supported by two guide rods on the sides. The lead screw is secured to a coupling, which in turn is attached to a motor. As the motor powers the rotation of the coupling, the attached lead screw also turns, which enables the forward and backward movement of the carriage. Now, a holder sits on the carriage, which supports two horizontal metal rods. At the end of the rods, there is a cap which connects those rods to a support platform onto which the nozzle is installed with the help of two screws. Figure 1b shows an isometric view of the nozzle, which is 15.8 mm × 9.8 mm × 2.64 mm in size and was designed using Fusion 360 software. Figure 1c depicts the nozzle at 50% opacity to show the internal configuration of the nozzle, and Figure 1d shows the longitudinal section view of the nozzle.

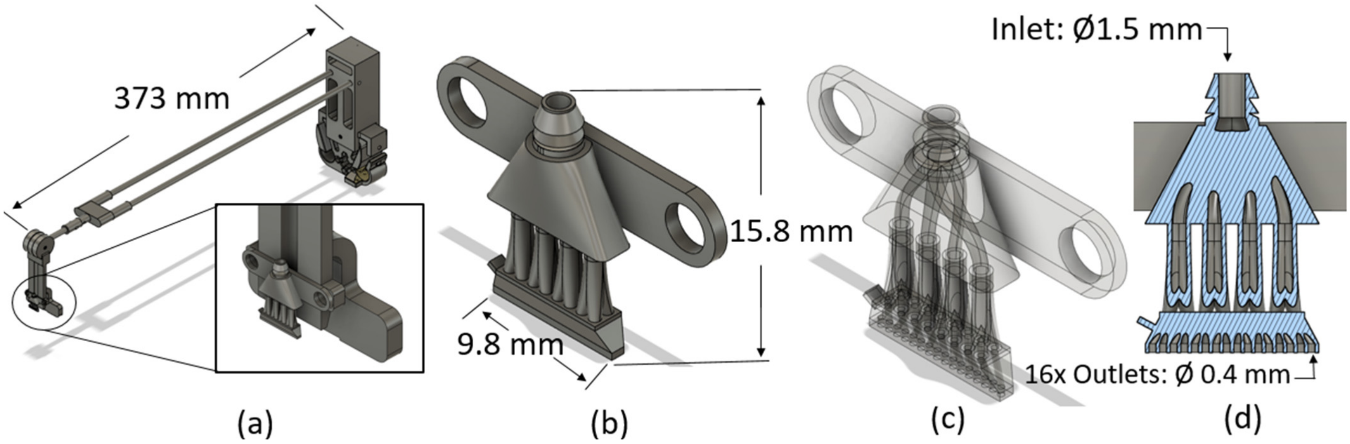

Figure 1. (**a**) The carriage with the nozzle; (**b**) the isometric view of the nozzle; (**c**) the nozzle with 50% opacity; (**d**) the section view of the nozzle.

The nozzle has one inlet of 1.5 mm diameter to let the resin in and 16 outlets of 0.4 mm diameters to extrude the fluid. Inside the nozzle, the inlet channel splits into four quadrants, as shown in Sec A-A in Figure 2. Those four quadrants then move down and take the shape of circles and are aligned in a linear position around halfway through the nozzle, as seen in Sec B-B. Those four circles then continue on to form four separate cylindrical tubes (Sec C-C), and each of those four tubes divides into four channels (Sec D-D), giving rise to sixteen smaller channels (Sec E-E). Finally, those sixteen channels align themselves linearly at the base of the nozzle to create outlets of 0.4 mm diameter each.

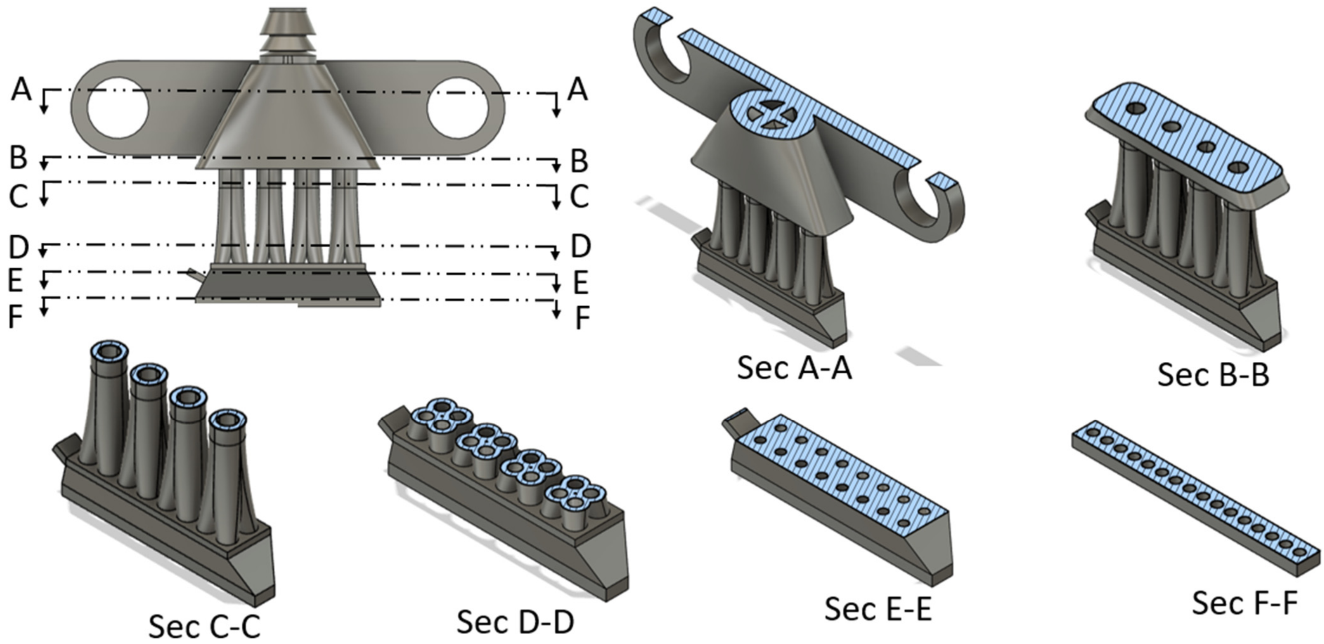

Figure 2. Cross-sectional views of the nozzle.

2.2. Simulation of Fluid Flow through the Nozzle

The simulation of fluid flow was performed using Ansys Workbench software (https://www.ansys.com/products/ansys-workbench, (accessed on 28 October 2024)) in the Fluid Flow (Fluent) module. As the software requires the fluid domain to run the simulation, the fluid domain of the nozzle was created in Fusion 360 and was imported into the Ansys workbench, as shown in Figure 3a. After that, the imported body was meshed with an element size of 0.9361 mm, resulting in a total of 362,427 elements, as represented in Figure 3b. Later, the inlet and outlets were defined.

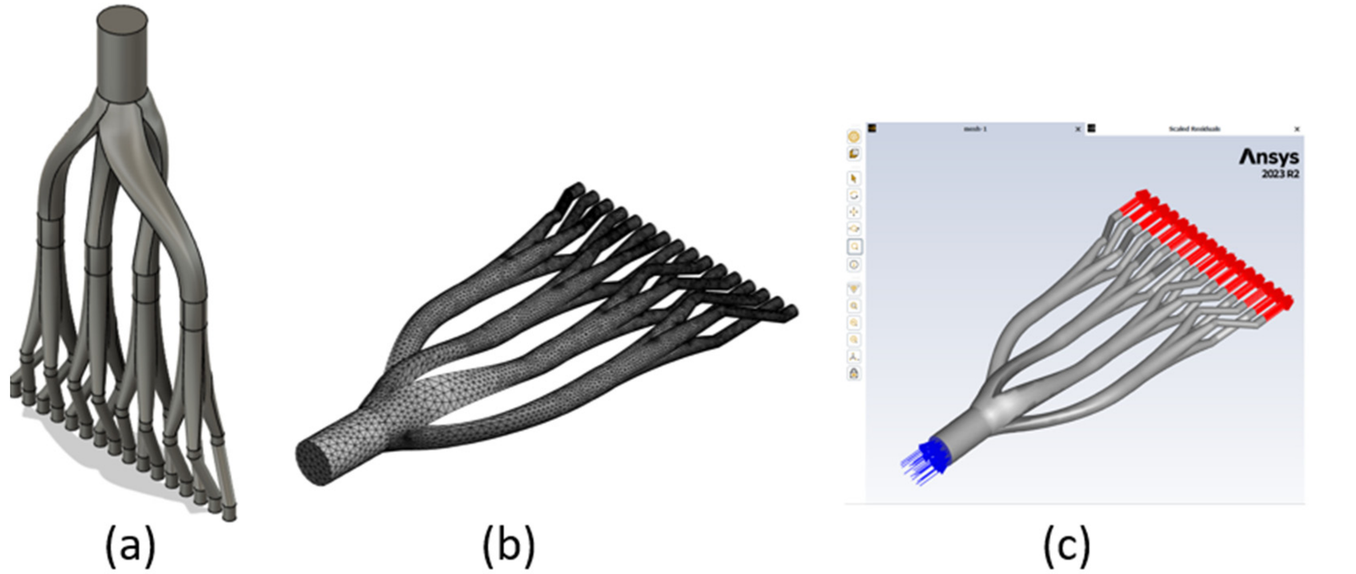

Figure 3. (**a**) Fluid domain inside the nozzle; (**b**) meshed body; (**c**) boundary conditions of inlet and outlets.

As the nozzle will be dispensing resin, to make the simulation more effective, a new material named "resin" was created in the solver setup, and the properties of Grey Resin (Formlabs, Somerville, MA, USA) were used to define the material [12]. This new "resin" material was assigned as the fluid for the simulation in the "cell zone condition" option. As for defining the boundary conditions, the velocity magnitude of the inlet was calculated to be 0.2150 m/s from the equation $Q = A \times v$, where Q, A, and v are the volumetric flow rate, cross-sectional area of the flow, and the velocity, respectively. The outlet types were changed to outflow, and the solution method scheme selected was SIMPLE. Figure 3c shows the boundary conditions selected.

3. Results and Discussion

The results of the fluid flow simulations conducted on the resin dispensing system yielded promising outcomes, indicating efficient performance and uniform resin distribution throughout the channels.

Firstly, the facet values of velocity magnitudes at the outlets were found to be consistent, ranging from 0.174 m/s to 0.191 m/s, as shown in Figure 4. This uniformity suggests a balanced flow distribution, crucial in ensuring consistent resin deposition across the printing area.

Additionally, contour profiles of the velocity magnitude were examined at four cross-sectional planes: the inlet (Plane A-A in Figure 5), the upper body (Plane B-B), the middle of the nozzle (Plane C-C), and the outlet (Plane D-D). At the inlet, the maximum velocity of 0.2150 m/s is dominant across the cross-section. However, as the fluid moves into four separate channels (Plane B-B), with the decrease in the cross-sectional area, the velocity magnitude increases, resulting in the maximum velocity magnitude on this plane being 0.41 m/s. It should be noted that, at this stage, the distribution of the velocities is not uniform across the four cross-sectional areas of this plane due to the irregular shapes of the cross-sections. However, as the fluid flow continues and goes through the circular channels (Plane C-C), the velocity contour starts to become uniform, and finally, when the fluid reaches the outlets velocity distribution across all channels exhibits excellent uniformity (Plane D-D), indicating smooth and controlled resin flow throughout the dispensing system. The contour across the longitudinal XZ plane in Figure 5 also shows a similar pattern: the concentration of higher velocity at the inlet, which starts to diminish as the fluid flows forward, with uniform velocity distribution at the end. This uniformity is particularly crucial at the outlet channels, where precise resin deposition is essential in achieving high-resolution prints.

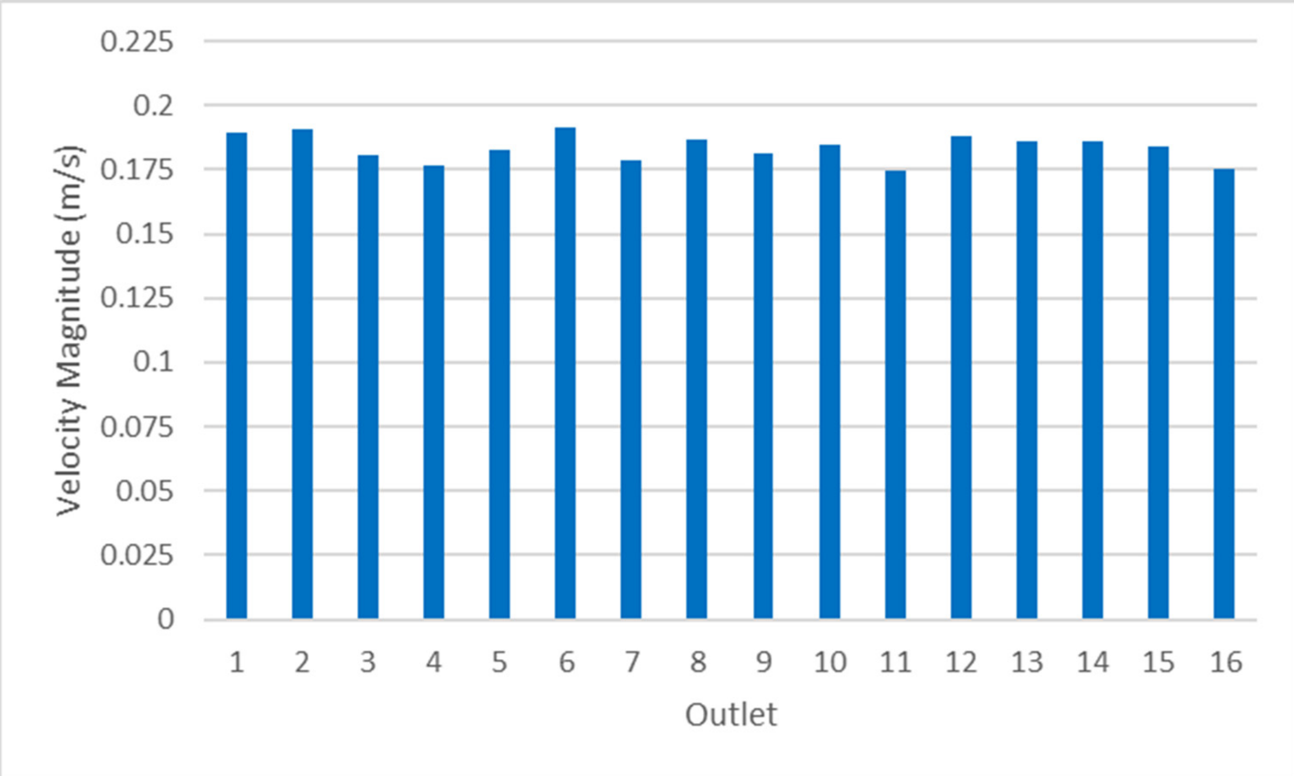

Figure 4. Graphical representation of the facet values of velocity magnitudes at the outlets.

The uniform velocity profile observed at the outlet channels can be attributed to the careful design of the dispensing system, including the specialized nozzle aimed at promoting laminar flow. By minimizing turbulence and ensuring a steady flow of resin, the nozzle facilitates consistent resin deposition, crucial in maintaining print quality.

Furthermore, the conservation of the continuity equation was evident throughout the simulation results. The continuity equation, which states that the volumetric flow rate into a system must equal the volumetric flow rate out, was effectively upheld in the fluid flow simulations, as calculated using the equation, $A_{inlet} \times v_{inlet} = A_{outlet1} \times v_{outlet1} + A_{outlet\ 2} \times v_{outlet\ 2} + \ldots + A_{outlet\ 16} \times v_{outlet\ 16}$, where A and v are the cross-sectional area and the velocity of the flow. This conservation ensures that the amount of resin dispensed matches the amount required for printing, preventing wastage and optimizing material usage.

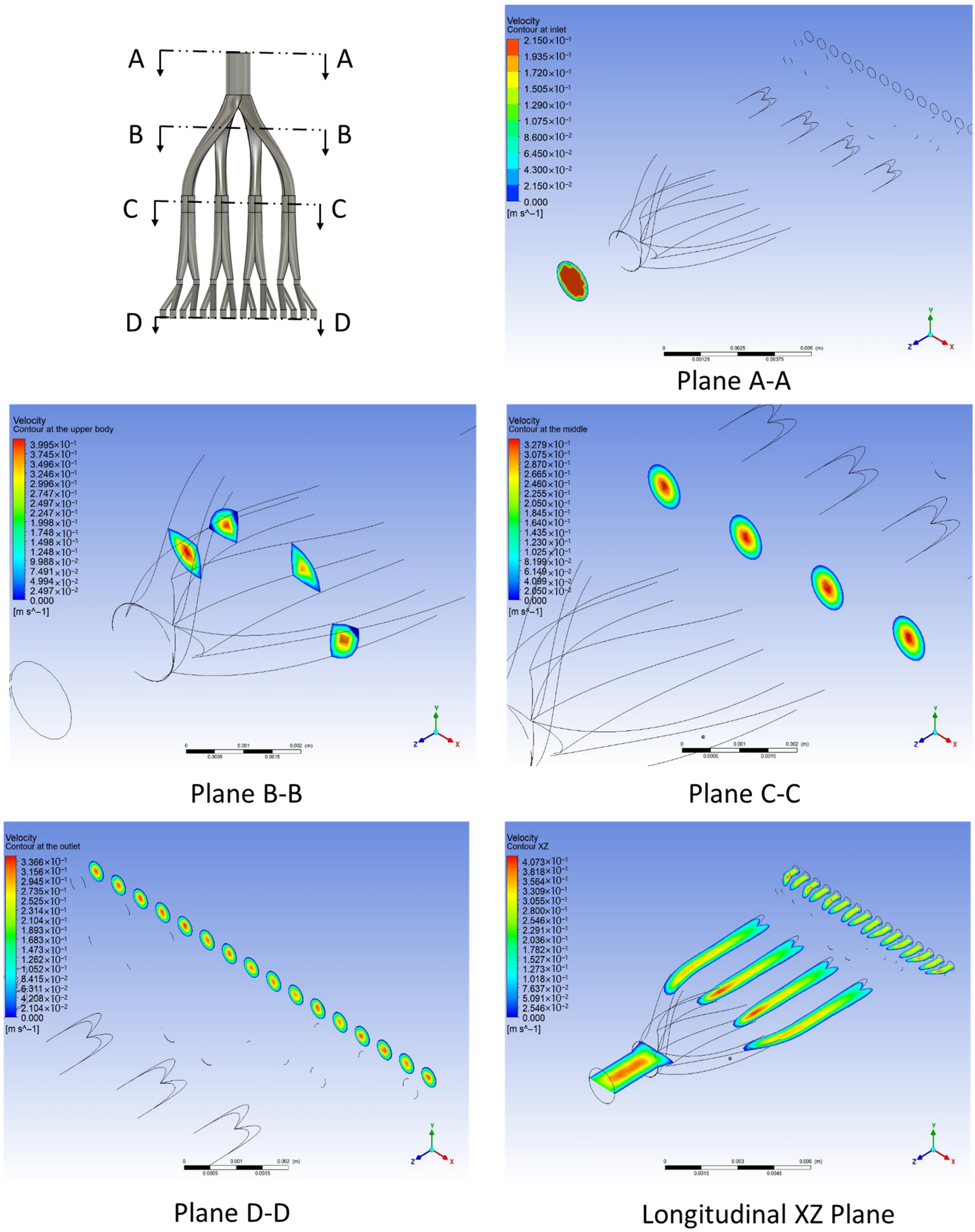

Figure 5. Contour profiles of velocity magnitude at different planes.

4. Conclusions

This study presents the design and simulation of a new resin dispensing technique designed for UV laser-based extrusion 3D printing. The goal is to address the limitations commonly associated with existing SLA and FDM technologies. The effectiveness of the dispensing system in achieving the consistent distribution of resin and sustaining a continuous flow of resin using simulations of fluid flow was confirmed. The findings demonstrated that the velocity magnitudes at the outlets were consistent, and there was a homogeneous velocity profile throughout all channels. This confirms that the system is capable of achieving accurate resin deposition. Moreover, the preservation of the continuity equation during the simulations emphasized the system's effectiveness in maximizing material utilization and reducing waste. In summary, the suggested resin dispensing system offers a favourable method of improving the precision of 3D printing, while also decreasing material usage and enhancing the quality of prints. Future research might prioritize the experimental verification and refinement of the technology for different printing purposes.

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Conflicts of Interest: The authors declare that they have no conflicts of interest.

References

1. Khondoker, M.A.H.; Asad, A.; Sameoto, D. Printing with Mechanically Interlocked Extrudates Using a Custom Bi-Extruder for Fused Deposition Modelling. *Rapid Prototyp. J.* **2018**, *24*, 921–934. [CrossRef]
2. DebRoy, T.; Wei, H.L.; Zuback, J.S.; Mukherjee, T.; Elmer, J.W.; Milewski, J.O.; Beese, A.M.; Wilson-Heid, A.; De, A.; Zhang, W. Additive Manufacturing of Metallic Components—Process, Structure and Properties. *Prog. Mater. Sci.* **2018**, *92*, 112–224. [CrossRef]
3. Hozdić, E. Characterization and Comparative Analysis of Mechanical Parameters of FDM- and SLA-Printed ABS Materials. *Appl. Sci.* **2024**, *14*, 649. [CrossRef]
4. Szykiedans, K.; Credo, W. Mechanical Properties of FDM and SLA Low-Cost 3-D Prints. *Procedia Eng.* **2016**, *136*, 257–262. [CrossRef]
5. Phillips, B.T.; Allder, J.; Bolan, G.; Nagle, R.S.; Redington, A.; Hellebrekers, T.; Borden, J.; Pawlenko, N.; Licht, S. Additive Manufacturing Aboard a Moving Vessel at Sea Using Passively Stabilized Stereolithography (SLA) 3D Printing. *Addit. Manuf.* **2020**, *31*, 100969. [CrossRef]
6. Xiao, R.; Ding, M.; Wang, Y.; Gao, L.; Fan, R.; Lu, Y. Stereolithography (SLA) 3D Printing of Carbon Fiber-Graphene Oxide (CF-GO) Reinforced Polymer Lattices. *Nanotechnology* **2021**, *32*, 235702. [CrossRef] [PubMed]
7. Lee, J.; Huang, A. Fatigue Analysis of FDM Materials. *Rapid Prototyp. J.* **2013**, *19*, 291–299. [CrossRef]
8. Heidari-Rarani, M.; Rafiee-Afarani, M.; Zahedi, A.M. Mechanical Characterization of FDM 3D Printing of Continuous Carbon Fiber Reinforced PLA Composites. *Compos. B Eng.* **2019**, *175*, 107147. [CrossRef]
9. Curti, C.; Kirby, D.J.; Russell, C.A. Stereolithography Apparatus Evolution: Enhancing Throughput and Efficiency of Pharmaceutical Formulation Development. *Pharmaceutics* **2021**, *13*, 616. [CrossRef]
10. Issabayeva, Z.; Shishkovsky, I. Prediction of The Mechanical Behavior of Polylactic Acid Parts with Shape Memory Effect Fabricated by FDM. *Polymers* **2023**, *15*, 1162. [CrossRef]
11. Samokhin, A.S. Syringe Pump Created Using 3D Printing Technology and Arduino Platform. *J. Anal. Chem.* **2020**, *75*, 416–421. [CrossRef]
12. Formlabs Grey Resin | Formlabs. Available online: https://formlabs.com/store/materials/grey-resin/ (accessed on 13 April 2024).