# Aesthetic and Modular Split Hook Prosthesis for Children

## Multi-Scale Additive Manufacturing Laboratory

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# Executive Summary

Children born with congenital upper limb (UL) differences or those who have acquired limb loss face unique challenges in their daily lives. For these young individuals, prosthetic devices serve as vital tools to restore lost function and enhance their quality of life [1]. However, the selection of prosthetic options for children involves a careful consideration of various factors, including functionality, aesthetics, comfort, and adaptability.

Split hooks tend to be the most functional body-powered terminal device prosthesis option for children as they are easy to use, have few parts, and allow for the grip of variously sized objects [2]. However, they are extremely unattractive, and the terminal device is typically made of bulky metal parts. There is a need for an aesthetic split hook design that is suited for the active and growing children who rely on them.

In this proposal, the split hook terminal device was re-imagined in a playful and aesthetic manner. Novel multi-material hooks were designed to offer rigidity and compliant gripping. Elements like a Lego plate or aesthetic placement of shape and colour were designed to add elements of play and personality to the design. This gives children the opportunity to have split hook parts in multiple designs; the increased modularity gives them more control of the prosthesis and how they want to look day-to-day.

Split hooks are typically cast from stainless steel for strength but can be bulky [2]. By using 3D printing, lighter filaments like ABS and Agilus30 can be used to achieve a sufficiently strong design. The design's robustness was verified using SOLIDWORKS force simulations under the maximum grip load of a child. To further lightweight the 3D printable design, NTopology was used to create a gyroid lattice infill. With this optimization, the parts should weigh 55g in total. This is a 21% reduction in the mass of the terminal device when compared to other metal split hook alternatives for children [2].

Split hook terminal devices can cost upwards of $10,000 [3]. Biomedical models similar in size and complexity to the proposed split hook terminal device were printed on the Stratasys J750 for under $200 [4]. The low cost of design allows for children to have multiple versions of the split hook in various colours, patterns and sizes. This unlocks the flexibility to interchange parts cost-effective way.

The modularity and playfulness of the proposed split hook terminal device will allow children the flexibility they deserve to customize their prostheses. This will have profoundly positive social impacts on their lives as they get to express their individuality.

## Introduction and Industry Overview

Children born with congenital upper limb (UL) differences or those who have acquired limb loss face unique challenges in their daily lives. For these young individuals, prosthetic devices serve as vital tools to restore lost function and enhance their quality of life [1]. However, the selection of prosthetic options for children involves a careful consideration of various factors, including functionality, aesthetics, comfort, and adaptability.

Children often encounter a myriad of UL prosthetic challenges that are distinct from those of adults. Children's rapid growth necessitates frequent adjustments and replacements of prosthetic devices, making traditional manufacturing methods costly and cumbersome; they will typically require a new prosthesis every 12 to 24 months until they are skeletally mature [5]. Children are also prone to damaging their prosthetic devices due to their active nature, hence requiring frequent replacement [6]. Moreover, societal stigma further complicates the acceptance and utilization of prosthetic devices among pediatric users [7]. Some children find prosthetics uncomfortable as they limit their freedom of movement and sensation [8]. UL pediatric prosthetics have an extremely high abandonment rate at 35-45% [9]; one of the many reasons is that children feel general-purpose prosthetics are not aesthetically acceptable, limiting their ability to express themselves [10].

Prosthetic solutions with varying levels of automation are currently available. Passive or cosmetic prosthetics are used for very young children but lack functionality [8]. They are the most cost-effective option at about $5,000-10,000 each and can be made to look realistic [11]. Moving from passive to body-powered prosthetics generally happens after age 5 [5].

Body-powered prosthetics allow for simplistic functionality in the form of being able to grab and grip [8]. These prosthetics utilize a harness worn by the user that pulls on a cord to manually actuate the design. Body-powered prosthetics are not aesthetically pleasing and tend to be expensive at up to $15,000 per unit [12].

Externally-powered options range from myoelectric prosthetics controlled by input from electrical signals generated by muscles in the residual limb to surgically invasive solutions, which are uncommon for children as they are still developing [10]. Myoelectric prosthetics offer the most functionality but are very expensive at $8,000-$80,000+ [13] [14]; they are not an option for most people due to the cost and maintenance required. Moreover, children often prefer simple functionality (open/close) over the complex, unnatural features myoelectric prosthetics have [15].

Split hooks tend to be the most functional body-powered terminal device prosthesis option for children as they are easy to use, have few parts, and allow for the grip of variously sized objects [2]. However, they are extremely unattractive, and the terminal device is typically made of bulky metal parts. There is a need for an aesthetic split hook design that is suited for the active and growing children who rely on them.

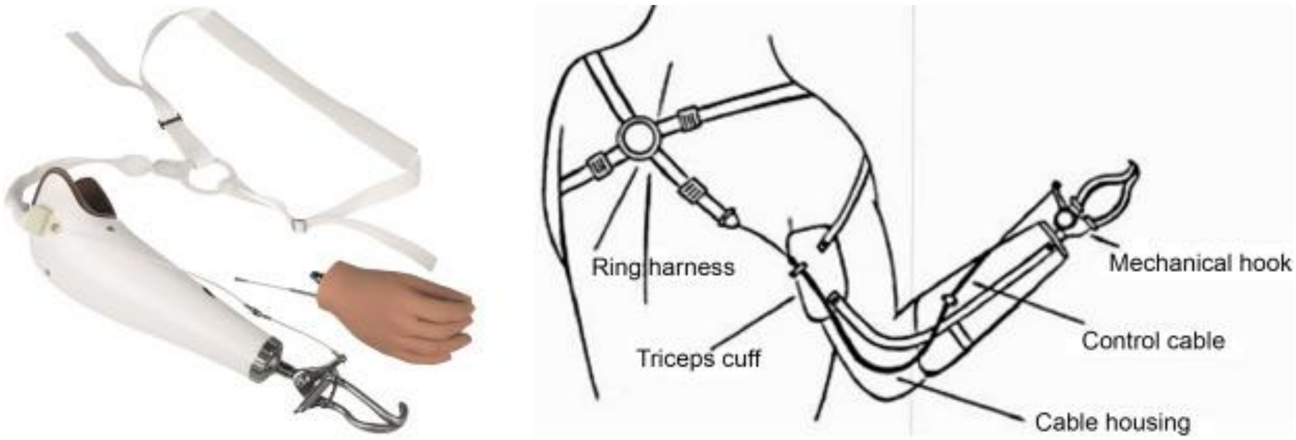


*Figure 1: Traditional Split Hook Terminal Device [16]*

## Design Requirements

This submission outlines the design of a modular and aesthetic split-hook prosthesis for children aged 5-10 years old. The design should satisfy the following functional criteria:

- The maximum grip force for the target child users ranges between 45N (5-year-old girls) to 160N (10-year-old boys) [17]; the design should be able to handle this load.
- The average finger length of the intended age range is 72mm (57mm to 100mm is the full range based on age and gender), so the hooks should have a similar hook length [18].
- The solution should be a terminal device that mounts to a standard, off-the-shelf body-powered harness; this harness can be seen in
- Figure 1.
- The solution should feature smooth contours and no pinch points for safe operation.
- The solutions should be lighter than metal split hook terminal device alternatives which weigh around 70g [2].

The design should satisfy the following aesthetic criteria:

- The design should allow for the customization of components through modular part swapping. This will allow children to change their prosthesis to reflect their individuality.
- Literature emphasizes the importance of play in child development [19]. The design should incorporate an element of play in the prosthesis.

## Design Process

A basic, 3D printable prosthesis body was designed to mimic generic split hook designs. The base is comprised of 2 halves that fit together in the center; one has a 3/8”-16 screw profile that fastens into a standard, off-the-shelf body-powered prosthesis harness. The other half rotates around a center shaft and connects to the cord of the harness, allowing the child to open and close the prosthesis. The hooks were designed to be ~72mm long and screw onto the base halves as seen in Figure 3, allowing for modularity and easy replacement. The outside of the hooks features a 2mm thick layer of softer filament, allowing children to get a better grip on objects with the device. The softer filament selected is Agilus30 and all other parts are made of Digital ABS Plus; refer to the next section for justification on this material selection. The associated properties of these materials were applied to the appropriate parts.

To verify the device could handle a grip load of 160N, the force was applied onto the terminal device via a SOLIDWORKS force simulation where it would develop the most bending moment – the end of a hook. The results of the simulation can be seen in Figure 2. The simulation is exaugurated but shows that the maximum displacement of the hook is 0.47mm, which is within the 2mm boundary of softer filament intended for the hook design.

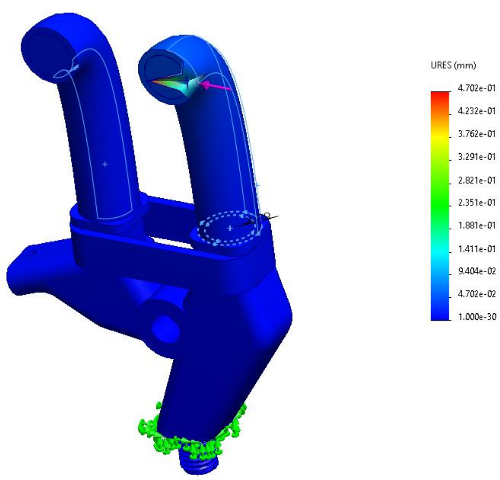


*Figure 2: Force Simulation*

Once the dimensions and simulations were completed, aesthetic improvements to the prosthesis were made. The base parts were smoothed and all sharp edges were removed. The hooks were given an outward bow to allow for a better grip on larger objects. Elements like a Lego plate or aesthetic placement of shape and colour were designed to add elements of play and personality to the design. This gives children the opportunity to have split hook parts in multiple designs; the increased modularity gives them more control of the prosthesis and how they want to look day-to-day.

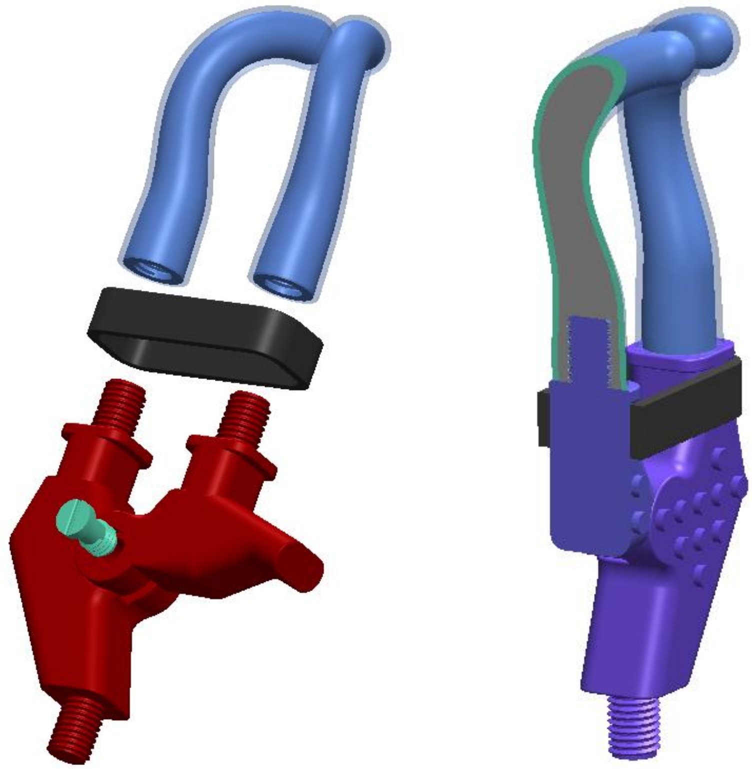

*Figure 3: Hook Exploded View Cross-Section*

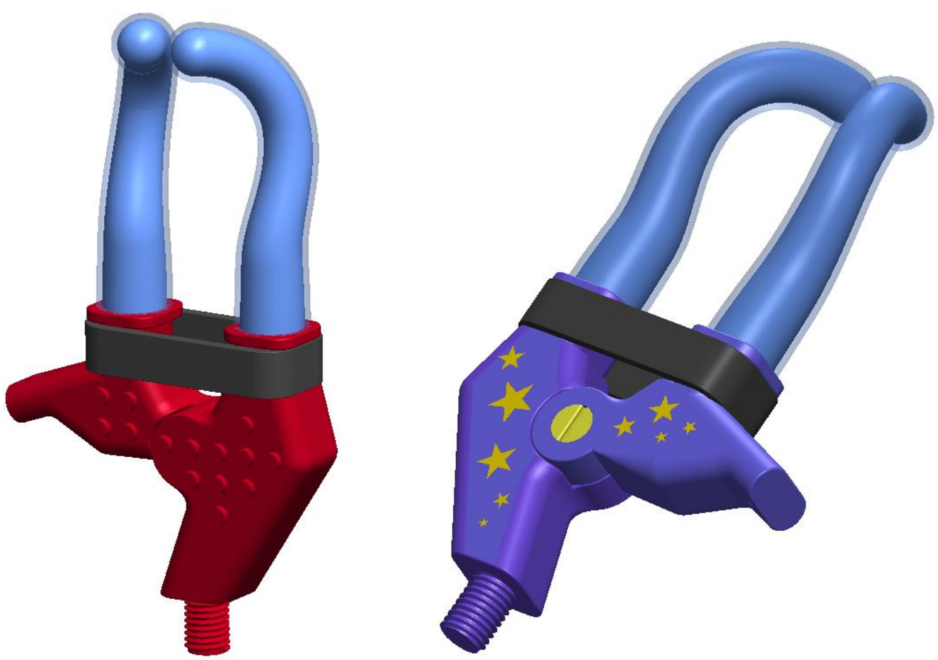

*Figure 4: Aesthetic and Modular Split Hook Design*

# Design Utilization of DDM Materials and Processes

To fabricate a prosthetic that combines different colours and materials, Stratasys PolyJet 3D printing technology may be employed [20]. This is an additive manufacturing technology that produces high-resolution parts by jetting and curing liquid photopolymer materials layer by layer. PolyJet technology is known for its ability to create smooth, detailed, and multi-material prototypes and products. The designed prosthesis may be printed on the Stratasys J750 using Digital ABS Plus [21] for the rigid body pieces (2 base pieces, center screw, and 2 hook centers) which are robust and strong enough to be used for prosthetics. Agilus30 [22] will be used as a rubber-like compliant coating on the hooks. This material allows the hooks to be robust to surface stresses while also having compliant, skin-like contact with objects a child may grip.

Split hooks are typically cast from stainless steel for strength but can be bulky [2]. By using 3D printing, lighter filaments like ABS and Agilus30 can be used to achieve a sufficiently strong design as previously shown. To further lightweight the 3D printable design, NTopology was used to create a gyroid lattice infill which is seen in Figure 5. A shell thickness of 4mm allows the wall of the prosthesis parts to be solid and robust while removing unneeded material in the center. An example of this process can be seen in Figure 5.

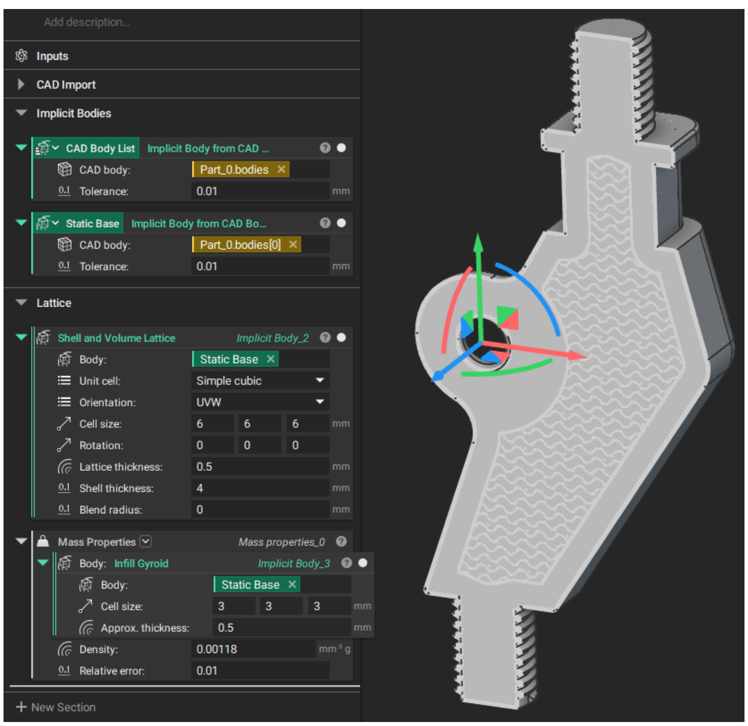

*Figure 5: Gyroid Infill Section View for the Prosthesis Base*

The masses of the parts were re-calculated in NTop; together, the parts should weigh 55g in total. This is a 21% reduction in the mass of the terminal device when compared to other metal split hook alternatives for children [2].

## Cost and Lifetime Analysis

Split hook terminal devices can cost upwards of $10,000 [3]. Biomedical models similar in size and complexity to the proposed split hook terminal device were printed on the Stratasys J750 for under $200 [4]. The low cost of design allows for children to have multiple versions of the split hook in various colours, patterns and sizes. This unlocks the flexibility to interchange parts cost-effective way.

Given the prosthesis was simulated to handle the maximum grip force of a 10-year-old boy, the design is expected to be robust to everyday wear. Moreover, similar prosthetics have a lifetime of 5 years [23]. Children will need to replace their prosthesis every year as they grow older and require larger geometries [5]. Cyclic loading simulations on ANSYS or Solidworks may be used to verify the design's robustness over the expected year-long usage period.

## Environmental, Health, Safety, and Quality Considerations

Specific global standards focused on ergonomics for children's UL prosthetics do not currently exist. However, various standards and guidelines related to prosthetics and orthotics may touch upon ergonomic considerations. These standards are often developed and maintained by organizations such as the International Organization for Standardization (ISO); relevant standards include ISO 10328:2016 (structural testing of lower-limb prostheses) and ISO 22523:2006 (clinical application of upper-limb prosthetics) [24]. The design may be further refined to align with suggestions in these standards.

Ideally, the only post-processing required when using PolyJet technology is the removal of support material used. Since parts can be 3D printed easily, the hooks can be replaced if they get worn or break. Given ABS and other filaments can be recycled back into filament, broken parts and support material can be reused [25]. This allows the manufacturing and reclamation process for the proposed 3D printed split hook to be environmentally conscious.

## Digital and Physical Infrastructure

The base design of the 3D printed prosthesis can be made available as an open-source design. This allows prosthetics designers a base to further customize parts. Given Stratasys PolyJet printers are expensive, larger organizations are likely the ones that could manufacture the split hook parts.

However, the design does not have to be exclusively manufactured using PolyJet technology; several more affordable FDM printers have multi-material capabilities that can also be used [26]. This allows hobbyists or anyone with access to public 3D printers to print the split hook terminal device. This manufacturing flexibility allows the supply chain of parts to be resilient if larger corporations are not able to deliver parts.

## Conclusions

Split hook terminal devices for children are functional yet not aesthetically pleasing. The redesigned split hook design proposed in this submission re-imagines the prosthesis by modernizing the design into aesthetic parts that can be easily assembled. These parts can be made in several colours and feature a novel, compliant coating on the hooks.

The modularity and playfulness of the proposed split hook terminal device will allow children the flexibility they deserve to customize their prosthesis. This will have profoundly positive social impacts on their lives as they get to express their individuality.

## Acknowledgements

The authors would like to thank nTopology, Inc. and SOLIDWORKS for supporting us with an educational license to their software for this project.

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